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B. T. GALLOWAY, *Chief of Bureau.*

THE LOOSE SMUTS OF BARLEY AND WHEAT.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., April 1, 1909.

Sir: I have the honor to transmit herewith a technical paper entitled "The Loose Smuts of Barley and Wheat," containing the results of recent researches by the Office of Grain Investigations into the life histories of loose smuts and the determination of methods for their prevention. These smuts have been on the increase in recent years, as satisfactory means of combating them have been unknown. The accompanying paper, prepared by E. M. Freeman, formerly Pathologist in the Office of Grain Investigations, at present a collaborator of the same Office, and Edward C. Johnson, Pathologist in the Office of Grain Investigations, not only gives much new information on the life histories of these important grain smuts, but also demonstrates a practical method for their prevention. I therefore recommend that it be published as Bulletin No. 152 of the special series of this Bureau.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE LOOSE SMUTS OF BARLEY AND WHEAT.

INTRODUCTION.

The loose smuts of barley and wheat have often been considered diseases of minor importance. Although this estimate may have been justifiable ten or fifteen years ago, it certainly is not warranted at the present time. In Wisconsin and Minnesota losses from loose smut of barley of 5 to 10 per cent are not at all uncommon, while greater losses sometimes occur. Loose smut of wheat often prevails to the extent of 3 or 4 per cent in Minnesota, and considerably higher percentages have been observed in that State and in other States. Losses exceeding half of the crop have been reported in a few cases, although these are comparatively rare. Undoubtedly the greatest loss at present is occasioned by the wide distribution of these smuts. They are practically coextensive with their host plants, and though they occur usually in small quantities the damage in the aggregate is large. They often are entirely unnoticed on account of their earliness and the absence of any conspicuous sign of them at harvest time.

The loose smuts of barley and wheat are to be considered enemies to cereal culture not only on the basis of the present damage which they cause, but also on account of the possibilities of their power of increase under favorable conditions. The barley smut in particular has demonstrated its power in Minnesota and Wisconsin, where the farmers are now wide awake to the danger. The seed of wheat and barley is infected one year, but does not produce a smutted crop until the next season, while the methods necessary for combating the disease are not simple or easily applicable. Such facts emphasize the dangerous nature of these fungous pests and make the determination of any successful method of prevention especially desirable.

DESCRIPTION OF LOOSE SMUT OF BARLEY.

There are two smuts of barley common in this country. The loose smut (*Ustilago nuda* (Jens.) Kell. & Sw.) is easily distinguished from the covered smut by its earlier appearance, by its olive-green spore mass as compared with a black spore mass in the latter, and by the early shedding of the spores, which are blown off by the wind almost as soon as the smutted head comes out of the leaf sheath. In covered smut the spore mass is compact and often persists as smut balls in the harvested grain. (See Pl. I, *d*, *e*, and *f*.)

The smutted plants head earlier as a rule than those not infected. The heading in both infected and normal plants is prolonged throughout a period of from four to fourteen days, depending on external conditions. However, the period of maximum smut development in a field always occurs at the maximum flowering time of the barley. Scattering heads on both infected and healthy plants appear until the time of harvest. Usually the smutted heads are elevated rapidly above those of the healthy plants, thus giving opportunities for a wide distribution of spores by air currents. The light weight of the smutted heads also assists them in maintaining an upright position in a heavy wind. In general, when a plant is infected every head is smutted. Occasionally, however, plants are found with some smutted and some sound heads. (See Pl. VI.)

In a smutted head usually every spikelet and every kernel is smutted. To this again there are not infrequent exceptions. When spikelets in an infected head escape the smut they ordinarily occur at the top. (See Pl. III, *b*.) In the field such heads are commonly found late in the season, i. e., shortly before harvest. Sometimes they occur in artificially infected plants when infection has taken place previous to the full flowering period.

In a smutted head as a rule each spikelet is entirely transformed into a smut mass. (See Pl. II.) The ends of the awns, however, frequently escape. These often remain as weak threadlike bodies on the end of the smut masses. The rhachis is never destroyed, and persists as a naked stalk after the spores have been blown off. In a smutted plant the smut occasionally extends to the top of the leaves, and large bract-like bodies, likewise smutted, are sometimes formed at the bases of the heads. These are probably the basal glumes or entire spikelets stimulated to abnormal development by the fungus. (See Pl. III, *e*.)

The smut masses when the head first appears are covered by a delicate grayish membrane. This soon bursts and sets free the powdery spores, which in a few days are blown off by the wind. In some seasons many of the latest formed smutted heads remain hard and black and fail to release their spores. The head, therefore, does not become powdery, but retains its mature form, and the spores are apparently never distributed. (See Pl. III, *d*.) In a normal smut head the smut mass is olive-green in color. The spores are approximately spherical and measure 5 to 7 by 5 to 6.5 μ in diameter. Seen under the microscope they are lighter colored on one side than on the other.

That there is a variation in the susceptibility to infection in different barleys seems clear from the fact that in variety tests on one-tenth-acre contiguous plats about equally exposed the different varieties show varying amounts of smut. The order of susceptibility in eight selected barley varieties, from the worst smutted to those showing no smut in 1906, was maintained in 1907. Whether this is due to an innate protoplasmic resistance during the stage of floral infection or whether it is due to differences in the time of maximum flowering period or to differences in the degree of opening of the glumes in the several varieties is not yet clear. Practically all barley varieties, both two-rowed and six-rowed, which have come under the writers' observation contain, however, some loose smut.

DESCRIPTION OF LOOSE SMUT OF WHEAT.

The loose smut of wheat (*Ustilago tritici* (Pers.) Jens.) in almost all of its characters resembles the loose smut of barley. There is a more striking difference between it and stinking smut, or bunt, of wheat than there is between the loose and covered smuts of barley. The bunt of wheat transforms only the kernels into smut balls, which do not break until the wheat is thrashed and often remain intact in the thrashed grain. The loose smut of wheat on the other hand discharges its spores even earlier than does the barley loose smut. (See Pl. I, *a*, *b*, and *c*.) The smut masses of the former are usually broken before the head gets out of the sheath, a feature not common in the latter. Loose smut of wheat is similar, however, to the loose smut of barley in all of its essential features, as just described. (See Pls. IV and V.)

The following slight differences may be noted: The smut appears at the flowering time of wheat, and thus usually in spring wheats a little later than in barley. Nothing has yet been observed in wheat similar to the bract-like or leaf-like bodies at the base of the smutted spike of barley. (See Pl. III, *e*.) The smut mass in wheat is darker than that in barley and approaches coal-black. The membrane covering it is even more delicate and breaks usually before the head is exposed to the air. The spores are spherical, 5.5 to 7.5 by 5 to 6 μ in diameter, and under the microscope are lighter colored on one side than on the other. The variation in susceptibility among wheat varieties is perhaps more marked than among the barleys. Some of the bearded spring wheats seem to be infected more easily than the common Bluestems. The smut is found, however, in practically all classes and probably all varieties of wheats.

The following records of loose smut of wheat were obtained in 1906 at McPherson, Kans., by Mr. V. L. Cory, for the Office of Grain Investigations:

> The greatest quantities of loose smut in wheat occurred in two Japanese varieties, a Roumanian wheat and a Kansas hybrid (Turkey Red × Zimmerman). The last-named variety gave 15 per cent. The appearance of this amount of smut is not readily explained. One Japanese variety (G. I. No. 1184–1, Japanese No. 1) contained 9 per cent of smut, and Onigara, another Japanese variety (G. I. No. 1695), 6 per cent. The Roumanian wheat contained about 8 per cent. The last three wheats are all early, and it is possible that on account of their earliness they are more easily subject to the wind-blown spores of loose smut than the later varieties. This does not explain the susceptibility of the hybrid mentioned above, as this was not an early variety. In regard to earliness of ripening, the Japanese wheats mentioned matured about June 22 or 23. The earliest wheat at the station was a Zimmerman which ripened June 16. It is an interesting fact that still another Japanese wheat (Japanese No. 4), which ripened at the time of the Zimmerman, was free from smut.

LIFE HISTORY STUDIES OF LOOSE SMUTS.

HISTORICAL REVIEW OF STUDIES.

In 1895[a] and 1896[b] Frank Maddox, of Launceston, Tasmania, produced what appears as the first evidence of "floral" or intra-seminal infection in the loose smuts of wheat and barley. In experiments undertaken to devise methods of prevention in the case of the loose smut of wheat he demonstrated that the ovaries of the wheat in the flowering stage could be "artificially smutted" by the application of the spores of loose smut. The grains developed from these ovaries were apparently normal, but when planted the following year almost invariably produced smutted plants. Mr. Maddox states:

> The loose smut germs on the grain or mixed with the soil are harmless and will not produce the disease. Artificially smutted is putting the smut germs on the ovary about the time the pollen is ripe, which will always reproduce the disease the following year. Pots sown in 1894, with smut added gave sound plants free from the disease, and the same pots sown in 1895 would reproduce the disease when artificially smutted, and grew sound plants in one pot. * * * The smut gets on the ovary at flowering time, the grain matures without any sign of being diseased. * * * Believe the spore is embedded beneath the epidermis or skin and is beyond reach of destruction by pickling.

The histological details of the infection were not worked out.

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[a] Maddox, F. "Experiments at Eastfield." Department of Agriculture, Tasmania, 1895.

[b] Maddox, F. "Notes and Results on Agricultural Experiments Carried on Under the Auspices of the Council of Agriculture of Tasmania at Eastfield, Newnham." Launceston, Tasmania, 1897.

Hori,[a] in discussing the question whether spores carried into the flowers may cause infection, says:

> Mr. S. Wakagawa, of our former branch station at Matsuto, carried out an experiment on this point early in 1897. He introduced the matured spores of *U. tritici* into the flowers of wheat in the same field by means of a forceps. The infected seeds were sown in the ordinary time of the autumn of the same year. In the following year the ears as soon as they appeared were found to be all smutted. Similar experiments made by Mr. K. Yamada gave the same result. Soon afterwards I obtained similar results in flower infection with *U. tritici* and *U. nuda*. Hence I concluded that the spores of those smuts which mature at the flowering time of the host, and may be scattered easily by the wind, will be retained in the inner side of the seed and give rise to the smut disease during the next flowering time of the host plant.

In 1903 Freeman [b] described an intraseminal infection of the darnel grass. The fungus which is very commonly found in this plant seldom, if ever, produces spores. It lives in the growing point of the darnel in a manner quite similar to that of the cereal smuts. Instead of forming spores in the ovary, as most smuts do, it lies in wait for the young embryo of the darnel and infects the growing point, thus passing from one generation of darnel to the next, always living in the stem-growing points and neglecting altogether, as far as is at present known, to produce spores. The histological details of this intraseminal infection were shown.

Brefeld,[c] in 1903, and Hecke,[d] in 1904, working independently and apparently without any knowledge of Maddox's work in Tasmania or Hori's investigations in Japan, again demonstrated the floral infection of the loose smuts of wheat and barley. The histological data of the growing-point infection were added to make the evidence of floral infection complete.

The life history of the loose smuts of wheat and barley may be briefly described as follows: The smut spores in the field are distributed by the wind at the flowering time of the grain plant. They are blown into the spikelets, find their way between the glumes, and come in contact with the young ovary, or stigma. Here they germinate; the germ tube penetrates the ovary wall and the fungus finds its way into the growing point of the embryo. The mycelium then continues to develop until the grain is ripe without giving any external evidence of its presence. It lies dormant inside of the seed until the grain germinates, when it continues to develop with the seedling, keeping pace with the growing point until the head is formed. It then invades all of the young spikelets and destroys them, replacing them with the smut spores.

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[a] Bulletin, Imperial Central Agricultural Experiment Station, Japan, vol. 1, No. 2. 1907. [English.]

[b] Philosophical Transactions, Royal Society of London, series B, vol. 196, pp. 1–27. 1903.

[c] Nachrichten aus dem Klub der Landwirte zu Berlin, No. 466. 1903.

[d] Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich. 1904.

The life histories of the loose smuts of barley and wheat thus differ widely from those of the covered smut of barley and the stinking smut, or bunt, of wheat, where the spores are not distributed to any extent at flowering time, but get on the seed either in thrashing, in the bin, or in handling in sacks or in machinery. The spores of the latter smuts are sown together with the grain and germinate at the same time. The fungus then invades the young grain plant as it emerges from the seed, grows along with it until maturity, and forms the smut balls in place of sound grains.

EXPERIMENTS IN LIFE HISTORIES OF LOOSE SMUTS.

In order to test the validity of previous investigations, experiments in inoculations were undertaken at St. Anthony Park, Minn., in 1906 and 1907. The seeds from the inoculated plants in 1906 were planted in 1907, and the 1907 inoculations were tested in 1908.

The inoculations were made in the fields in 1906 and in special plats in 1907. Various methods as described later were employed. In testing the effect of inoculation at different stages of the flower, the following letters were used to designate the condition of the majority of flowers in the spike:

a—Before the stamens are mature.
b—At maturity of stamens.
c—Ovary just commencing to enlarge after fertilization.
d—Ovary one-third mature size.
e—Ovary two-thirds mature size.

The use of plus and minus signs serves to indicate intermediate conditions.

After inoculation some heads were covered with paraffin bags or with tissue paper, while others were left uncovered. The seeds obtained were treated before sowing with a solution of 2½ parts of formalin in 1,000 parts of water for two hours in order to insure the prevention of any infection from clinging spores of either loose or covered smut.

Fresh spores from mature smutted heads were always used as inoculating material. The spikelets were prepared for inoculation in some cases by cutting off the glumes near the base of the awns, thus leaving a slight opening between the tips of the glumes. This usually resulted in the loss of a considerable number of seeds where the flowers were in early stages of development. Other heads were left with their awns intact. The smut was applied on some heads by rubbing or brushing the outside; on others it was placed directly on the stigma and ovary by opening the glumes (as is done in artificial cross-pollination) and applying the smut with a brush or forceps. In a few cases the heads were moistened by a fine spray of water from an atomizer. A six-rowed barley (Minnesota No. 105) and a bearded spring wheat (Minnesota No. 188) were used as host plants. Both varieties produced in the field tests an average maximum of approximately 3 to 4 per cent of loose smut.

Three loose smuts were used: *Ustilago tritici* (Pers.) Jens. on wheat, *Ustilago nuda* (Jens.) Kell. & Sw. on barley, and *Ustilago lorentziana* Thüm. on wild barley (*Hordeum jubatum*). Cross-inoculations, i. e., from barley to wheat and wild barley, from wheat to barley, and from wild barley to barley, all produced negative results. The three smuts are therefore considered distinct species, incapable of transfer to the other hosts. The covered smut of barley was likewise found unable to produce infection in the flower of barley.

TABLE I.—*Results of inoculations of barley with loose smut of barley, St. Anthony Park, Minn.*

INOCULATIONS MADE IN 1906; PLANTS MATURED IN 1907.

Method of inoculation.	Stage of flower inoculated.	Plants produced from inoculated seed.	Smutted plants.	
		Number.	*Number.*	*Per cent.*
Spores rubbed on the heads; heads not covered	a	29	14	49
	c	47	23	49
	d–e	55	0	0
	e+	48	0	0
Spores rubbed on the heads; heads covered	a–b	21	4	19
	c+	22	6	*28
	e+	118	0	†0
Spores placed on ovary; covered	a–b	14	9	64
INOCULATIONS MADE IN 1907; PLANTS MATURED IN 1908.				
Spores on ovary; heads covered	a–b	1	1	100
	b	2	2	100
	c	12	12	100
	c–d	9	8	89
	d	18	9	50
	e and e+	7	0	0
Glumes cut; spores brushed on heads; heads covered	b	22	1	5
	c	40	2	5
	c–d	18	0	0
	d	14	1	7
	d–e	30	1	3
Glumes not cut; spores brushed on heads; heads covered	c	65	1	1.5
Glumes not cut, spores brushed on heads; heads not covered.	a	4	0	0
	a–b	6	0	0
	b	16	0	0
	c–d	5	0	0
Glumes cut; spores brushed on heads; heads not covered	a	29	0	0
	b	26	0	0
	b–c	70	1	1.4

* Heads sprayed with water when inoculated.
† Part (37 plants) sprayed with water when inoculated.

TABLE II.—*Summary of Table I, showing the effect of the stage of anthesis on infection with loose smut.*

INOCULATIONS MADE IN 1907; PLANTS MATURED IN 1908.

Stage of flower at inoculation.	Plants produced from inoculated seeds.	Smutted plants.		Partially smutted plants.	Healthy heads in partially smutted plants.
	Number.	*Number.*	*Per cent.*	*Number.*	*Per cent.*
a and a-b	64	27	42	22	35
c and c+	69	29	42	0	....
d-e	55	0	0	....	....
e+	166	0	0	....	....
INOCULATIONS MADE IN 1907; PLANTS MATURED IN 1908.					
a to a-b	40	1	2.5	....	....
b to b-c	136	4	3.0	1	10
c to c-d	149	23	15.0	4	30
d to d-e	62	11	17.0	....	....
e+	7	0	0	....	....

TABLE III.—*Results of inoculations of wheat with loose smut of wheat, St. Anthony Park, Minn.*

INOCULATIONS MADE IN 1906; PLANTS MATURED IN 1907.

Method of inoculation.	Stage of flower inoculated.	Plants produced from inoculated seed.	Smutted plants.	
		Number.	*Number.*	*Per cent.*
Spores placed on ovary; heads covered	c?	31	8	26
Spores rubbed on heads; heads covered	c?	97	10	10
INOCULATIONS MADE IN 1907; PLANTS MATURED IN 1908.				
Spores placed on ovary; heads covered	b-c	22	7	32

In 1906 the inoculations recorded in Tables I and II, except that on August 11, were made on July 10 and 11 and the seeds planted May 11, 1907; in 1907 they were made on July 10 and 23 and the seeds planted April 23, 1908.

The 1906 inoculations recorded in Table III were made on July 6 and the seeds planted on May 13, 1907; the 1907 inoculations (Table III) were made on July 23 and 25 and the seeds planted on April 16, 1908.

The results as shown in these tables establish clearly the floral or intraseminal infection of the loose smuts of barley and wheat in this country. Inoculation in the flower produced in some heads 100 per cent of infection.

On account of the variation in the stage of flowering found in almost any head of wheat or barley, the stage designated in the table is to be interpreted as the average in that head. A common condition illustrating this variability is the following: In many heads of barley examined on July 11, 1907, stage *d* prevailed at the center of the head and stage *c* at the bottom. At the tip the flowers were for the most part slightly in advance of the base, i. e., *c–d*. The optimum time for infection is the full flowering period, viz, stage *c*. Success is common in the earlier stages, even when the stamens are green (*a*). Infection seldom, if ever, takes place in stage *e*, i. e., when the ovary is about two-thirds its natural size. The partial successes in stages *d–e* are undoubtedly due to the *d* spikelets. It may be concluded that inoculation succeeds best just after fertilization of the egg cells, when the embryo has commenced to grow, as shown in the enlargement of the ovary. This agrees with Freeman's results with darnel, where infection took place as soon as the embryo had developed the "anlage" of a stem-growing plant.

At stage *e* and beyond, either the epidermis of the ovary wall or the newly formed aleurone layer is perhaps impenetrable to the germ tubes. The stigma, moreover, has dried and probably can not transmit the germ tube. The conditions previous to stage *c* present interesting data especially in the 1906 inoculations (Tables I and II). Here a striking difference is seen between the effects of inoculation on stage *c* and the earlier stages. (See Table II.) In the former every seed inoculated produced completely smutted plants, i. e., every head was smutted. In the latter 22 out of 27 plants were only partially smutted, and the average number of sound heads was 35 per cent of the total number. It is seen that this result was not duplicated in the 1907 inoculations, where *c* stages exhibited a fairly large number of partially smutted plants (4 out of 16), with 30 per cent of sound heads. Whether this escape of heads in a smutted plant is due to the initial condition of the flowers at the time of inoculation, to the accidental escape of lateral branches in the subsequent growth, or to weather conditions inimical to the best development of the fungus can not be stated until the histological details of the infection and subsequent development are fully understood.

In accordance with what would be expected, the most efficient method of inoculation is that of placing the smut directly on the stigma and ovary, although the rubbing method is also efficient, producing 49 per cent in some cases. The rubbing tests were more successful in 1906 than in 1907, as a result, perhaps, of different weather conditions at the time of inoculation. The season of 1907 was abnormally dry. This may have prevented the spores from being washed into the flower, or the moisture may have been insufficient for spore germination. Covering the heads after inoculation does not seem to be essential.

In spite of the remarkably close pollination in barley the glumes may often be found open one-sixteenth of an inch (and in some cases even more) at the time of maturity of the stamens. They are, of course, forced apart a little later to allow the stamens to be extruded. It is undoubtedly during these open periods that the smut spores gain entrance to the flower, perhaps most frequently at the earlier one. That the opening is as wide in all flowers as that stated above is extremely improbable. Varietal differences based on the opening habits are to be expected, though up to the present none have been observed. In addition, the state of the weather during flowering time in a field must exert a great influence on distribution. The results of the following test are probably explainable only on the basis of unfavorable weather conditions. Eighty-two seeds were obtained in 1907 from wheat heads in which the glumes had been cut as previously described. These were then left exposed to natural infection. Less than 2 per cent of loose smut resulted, while 2 to 5 per cent was found among uncut control plants in the same plats.

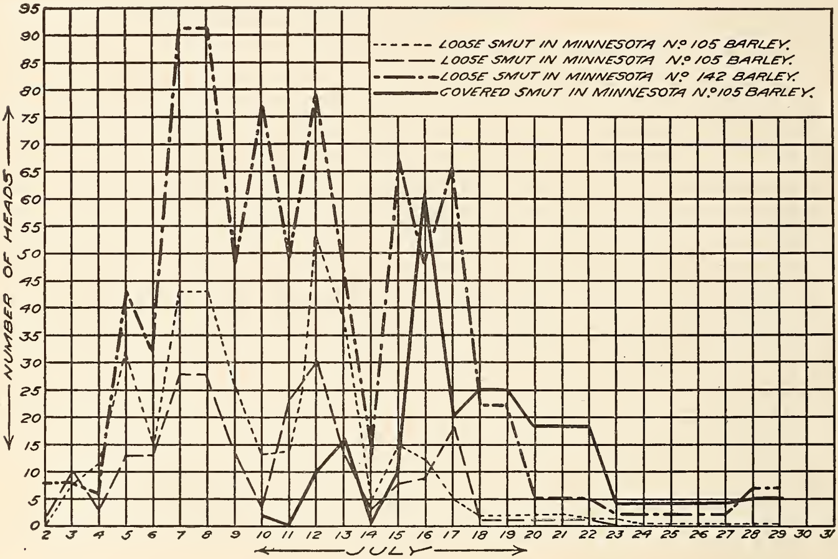

FIG. 1.—Diagram showing the daily record of barley smut at St. Anthony Park, Minn., in 1907.

The flowering period in a pure variety is, of course, fairly uniform. Stages *c* to *d* were quite general in the fields at St. Anthony Park in the barley varieties known as Minnesota Nos. 105 and 142 on July 10 and 11, 1907. Figure 1 shows the number of smutted heads picked from several one-fortieth-acre plats of barley which were rogued carefully each day. There were two plats of Minnesota No. 105 and one plat of Minnesota No. 142. One plat of Minnesota No. 105 contained covered smut, as shown in the diagram, while the other, which had been treated with formalin, had none. Minnesota No. 142 barley did not have any covered smut. The approximate median date of the maximum period of loose smut in 1907 was July 10 in Minnesota No. 105 and July 12 in Minnesota No. 142. The corresponding date for the covered smut was July 18, approximately one week later.

It will be seen that the full flowering period in 1907, viz, July 10 and 11, fell exactly on the median date of maximum smut. The later appearance of covered smut is explained in its spore habit of clinging to the grain, as do the spores of the stinking smut of wheat. The effective formalin treatment previously mentioned is strong evidence that this is the case.

The mere fact of close proximity of a head of barley or wheat to a smutted head does not necessarily insure infection. Heads of barley (Minnesota No. 105) growing close to smutted heads in 1906 were selected, and 324 plants from this seed matured in 1907 with an average of 2.2 per cent of smutted plants—less than the field average for this variety in the same year.

The phenomena of partially smutted heads introduce interesting possibilities. In such heads on wheat, for instance, various conditions may be found. In some spikelets observed in 1907 only the glumes escaped the smut; in some, the ovary alone was attacked, the ovary wall remaining apparently uninjured; in others, no smut appeared, but the ovary was aborted, and in still others apparently sound grains were produced. In partially smutted heads the upper spikelets of the head most commonly escape. Occasionally, however, the middle spikelets are sound while the spikelets above and below are smutted. No cases have been observed where the basal spikelets escape the smut. In regard to partially smutted heads the following questions arise: Do the sound grains entirely escape infection as the head develops or do they contain the fungus in a dormant stage after an ineffectual attempt to form spores has been made? The possibility of the latter condition is actually paralleled in the case of the fungus of the darnel, where the parasite regularly gets into the seeds and infects the young embryos, but does not form spores. To test this possibility sound seeds from smutted heads were collected in 1906 and 1907 and planted during the following years. To avoid external infection these were treated with formalin before planting. From such seed from the 1906 crop 98 plants of barley developed 2 per cent of smut in 1907, and 51 plants from seed from the 1907 crop developed 2 per cent of smut in 1908. In each case the amount of smut did not reach the average (3 to 4 per cent) in the field crop. It seems clear, therefore, that the sound grains in a smutted head escaped infection as far as the mycelium inside of the infected head is concerned. Similar results were obtained with loose smut of oats.

INFLUENCE OF TIME OF PLANTING ON LOOSE SMUT.

In Table IV are shown the results obtained by planting spring wheat and barley at different times to determine what effect the time of planting may have on the development of the smut. As infection took place in 1906, this is merely a test of the development of the fungus in 1907 in plants grown from the already infected seed.

TABLE IV.—*Influence of time of planting on loose smuts of barley and wheat, St. Anthony Park, Minn., 1907.*

Date of planting.	Barley, Minnesota No. 105.		Barley, Minnesota No. 142.		Wheat, *a*, Minnesota No. 188.		Wheat, *b*, Minnesota No. 188.	
	Number of heads.	Smut.	Number of heads.	Smut.	Number of heads.	Smut.	Number of heads.	Smut.
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*
Apr. 23	....	....	759	5.53	....	....	981	1.21
25	....	....	901	5.87	....	....	1,038	1.54
26	587	1.36	....	....	761	1.31	....	....
May 6	515	.58	837	6.81	672	1.33	887	2.14
7	517	1.35	1,097	5.64	748	1.81	1,002	.89
8	788	1.65	774	5.42	831	1.56	933	1.50
9	324	2.79	743	6.46	844	.94	848	.94
10	392	1.78	551	4.53	324	2.77	751	1.33
11	281	1.78	740	4.58	517	2.70	1,025	2.14
13	325	.92	591	7.10	491	4.07	611	1.47
14	338	1.47	....	....	517	2.51	....	....
15	110	2.72	897	6.35	581	1.37	954	3.24
16	446	1.79	695	5.46	598	3.17	740	2.43
17	359	1.39	940	4.04	745	2.68	882	1.02
20	217	3.68	665	5.56	622	2.41	558	1.07
22	249	2.81	662	5.13	545	2.56	611	1.47
24	342	1.16	843	3.91	556	3.05	553	1.44
27	191	3.15	679	3.94	441	3.40	428	2.33
29	240	1.20	712	5.05	362	1.93	351	1.70
31	262	1.14	571	3.46	335	2.08	426	1.40
June 3	200	3.5	516	2.32	252	1.98	276	.72
5	173	1.73	742	2.56	252	.79	266	1.12
7	259	.38	306	2.74	227	.44	207	.48

Barley (Minnesota No. 105) and wheat, *a* (Minnesota No. 188), were planted in a dry, sandy soil with good drainage, while barley (Minnesota No. 142) and wheat, *b* (Minnesota No. 188), were planted in a fairly heavy, low-lying, moist soil. The time of planting had no marked effect on the amount of smut. Wheat on the sandy soil contained on an average slightly more smut than that on the heavier, low-lying soil, but the difference was not great. The latest plantings showed a slight decrease. This decrease, however, is not consistent, and is certainly too small to be of practical importance, since comparatively few heads filled and the plants were badly stunted. Similar results with the same wheat and barley (Minnesota No. 188 and Minnesota No. 105, respectively) planted at intervals of about four to six days, from April 22 to May 28, were obtained in 1908.

It may be concluded, therefore, that the time of planting within the range of dates attempted does not affect to any appreciable degree the development of the loose-smut fungus in the host plant as far as spring wheats and spring barleys are concerned.

In regard to winter wheats and winter barleys the case may be different. The following experiment was performed by Mr. A. H. Leidigh, at Amarillo, Tex., in 1905 and 1906, with Tennessee Winter barley. Plantings were made from the same bulk of seed on September 21, October 12, and November 11, 1905. In 1906 the three plantings contained very different amounts of smut. The earliest, that of September 21, developed 10 to 12 per cent of smut; the October 12 planting (about the usual time of planting for that section of the country) developed 22 to 25 per cent of smut, and the November 11 planting showed less than 1 per cent. In the same season, 1906, barley from the same bulk of seed developed at Chillicothe, Tex., about 27 per cent of smut. There seems to be no doubt that the time of planting had in this case a very considerable effect on the amount of smut. Results exactly similar to these were obtained with Japanese wheat and barley by Hori,[a] who says, in part:

> It is a peculiar phenomenon that if the seeds are sown early in the season the smut proportionally increases, and vice versa. * * * In consequence the smut is comparatively rare on wheat and barley cultivated in the rice fields, because the labor of harvesting the rice, draining, plowing, and drilling delays the sowing at least one to one and a half months. That fact is no doubt due to the difference between the germinating temperature of the smut spore and that of the seeds.

It is thus seen that the results in Japan were exactly similar to those obtained by Mr. Leidigh, at Amarillo, since the Japanese wheats and barleys were winter varieties. In general, the explanation given by Hori seems probably correct, namely, that the mycelium of the loose smut requires a higher minimum temperature for germination and growth than does the wheat or barley seed. The fact that the spring wheats and barleys do not show a decrease on the earliest dates in the experiment outlined in Table IV is possibly explained by the supposition that the required temperature difference did not exist under spring grain conditions in that locality.

TREATMENTS FOR LOOSE SMUTS.

HISTORICAL REVIEW OF TREATMENTS PREVIOUSLY APPLIED.

All previous experiments with these smuts demonstrate that ordinary seed treatment is of no avail. Jensen[b] (1887–1889) devised what is known as the modified hot-water treatment, in which soaking of barley in cold water for eight hours, followed by treatment in hot water at 127° F. for five minutes, destroyed the smut. Kellerman and Swingle[a] cite the experiments made in Denmark by Jensen and add: "We therefore strongly recommend his latest form of the treatment, which is as follows: Soak the barley for four hours in cold water and then let it stand four hours longer in a wet sack. Finally dip and drain, as directed in the treatment for oat smut, for five minutes in water of a temperature of 126°–128° F., after which dry and plant as in case of oats." No recommendation of the modified hot-water treatment for the prevention of loose smut of wheat is made in this or in Jensen's reports. Kellerman[b] records numerous trials where the wheat was treated for five minutes at various temperatures after being "previously soaked." He concludes, however, that "no grounds, based on actual experiments, appear to exist for recommending the treatment of the seed with hot water or any other fungicide."

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[a] Bulletin of the Imperial Central Agricultural Experiment Station, vol. 1, No. 2, pp. 163–176. 1907. [English.]

[b] Jensen, J. L. Nye Undersogelser og Forsog over Kornsorternes Brands, 1887, p. 15; Propagation and Prevention of Smut in Oats and Barley, Journal of the Royal Agricultural Society of England, vol. 24, second series, part 2; Le Charbon des Cereales, Copenhagen, July, 1889.

Swingle,[c] basing his recommendations on experiments in Kansas planned by Kellerman and Swingle, carried out by Swingle and reported by Kellerman in 1891, in 1894 first recommended a modified hot-water treatment for loose smut in wheat as follows:

> Grain must be soaked four hours in cold water, then set away about four hours more in wet sacks, and finally treated as directed above, but only for five minutes, at 132° F. In planting use one-half more seed per acre to compensate for seed killed by the treatment. For preventing both of the smuts affecting barley the grain should be soaked as directed above and treated five minutes at 130° F., 2 degrees lower than for wheat. * * * It [loose smut of wheat] can, however, be combated by treating enough wheat to furnish seed for the following year, and this should be done when any considerable per cent of the crop is affected.[d]

In 1898 the same author made the same recommendations for preventing loose smuts of wheat and barley, but for the barley treatment added that "this treatment does not injure the seed."[e]

Maddox,[f] in 1896, found that by carefully picking out the loose smut heads in wheat for two years in succession in a 4-rod plat seed was obtained for a half acre which was almost entirely clean of smut.

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[a] Kansas Agricultural Experiment Station, Second Annual Report, 1889, pp. 283–284.

[b] Bulletin 22, Kansas Agricultural Experiment Station, 1891.

[c] Yearbook of the United States Department of Agriculture, 1894, p. 417.

[d] Yearbook of the United States Department of Agriculture, 1894, p. 412.

[e] Farmers' Bulletin 75, United States Department of Agriculture, p. 14.

[f] Maddox, F. Loc. cit.

Moore,[a] working on loose smut of barley in Wisconsin, obtained favorable results by soaking seed for twelve hours in cold water, draining one hour, and treating for ten minutes in water at 130° F.

Hori [b] was likewise able to prevent loose smuts by soaking the seed for seven hours in cold water, immersing it for a few minutes in water at 122° F. (50° C.), and finally treating it in water at 131° F. (55° C.) for five minutes.

EXPERIMENTS IN THE TREATMENT OF LOOSE SMUTS.

Jensen's treatment for loose smut was devised without knowledge of the life history of the smut. Since there seemed to be a possibility of further perfecting it, experiments were undertaken chiefly with this method.

EFFECT OF TREATMENT ON THE GERMINATION OF WHEAT AND BARLEY.

Preliminary tests were made at Washington, D. C., in February, 1907, of the effect on barley and wheat of soaking, followed by hot-water treatment. The germination tests were made in the Seed Laboratory of the Bureau of Plant Industry by W. L. Goss. Tables V and VI present the practical results of these tests, showing the duration of the soaking in cold water and the highest temperatures of hot water used, with the length of time of treatment, which resulted in a seed germination of 60 per cent or more. The results in all cases show a very marked decrease in germination when the temperatures are raised above those given in the table. Small quantities of seed were soaked in beakers for the specified time, then quickly drained, placed in wire baskets and immersed in a large tub of hot water in which the recorded temperatures were accurately maintained. The periods of treatment in hot water were 5, 10, and 15 minutes.

The percentages of the germination after treatment are also given. Each table is arranged to show (1) the highest temperature and (2) the longest duration of the hot-water treatments which gave a germination of 60 per cent or more. The control germinations of unsoaked seeds without any hot-water treatment were in all cases above 90 per cent.

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[a] Wisconsin Agricultural Experiment Station, 23d Annual Report, 1906, pp. 270–274.

[b] Loc. cit.

TABLE V.—*Effect on the germination of wheat (Spring Wheat Minnesota No. 169) of treatment with hot water preceded by a soaking in cold water, showing the highest temperature and the time limits with various treatments, Washington, D. C., February, 1907.*

ARRANGED ACCORDING TO TEMPERATURES.

Period of soaking in cold water.	Temperature of hot water (maximum).	Duration of hot-water treatment with little or no injury to germination.
Hours.	*°C.*	*Minutes.*
12–13	52.0	5, 10, or 15.
12–13	54.4	5.
6–7	52.0	5, 10, or 15.
6–7	54.0	5, 10 (70 per cent), or 15 (65 per cent).
6–7	56.0	5.
4–5	52.0	5, 10, or 15.
4–5	54.0	5, 10, or 15 (60 per cent).
4–5	56.0	5 (73 per cent).

ARRANGED ACCORDING TO DURATION OF TREATMENT.

Period of soaking in cold water.	Duration of hot-water treatment.	Temperature of hot-water (maximum).	Germination.
Hours.	*Minutes.*	*°C.*	*Per cent.*
12	15	52.0	81
12	10	52.0	86
12	5	54.4	84
6–7	15	54.0	65
6–7	10	54.0	70
6–7	5	56.0	73
4–5	15	54.0	60
4–5	10	54.0	86
4–5	5	56.0	73

TABLE VI.—*Effect on the germination of three six-rowed varieties of barley (Oderbrucker, G. I. No. 537; Mansury, G. I. No. 170; Kitzing, G. I. No. 189) of treatment with hot water preceded by a soaking in cold water.*

ARRANGED ACCORDING TO TEMPERATURES.

Period of soaking in cold water.	Temperature of hot water (maximum).	Duration of hot-water treatment with little or no injury to germination.
Hours.	*°C.*	*Minutes.*
12–13	52	5, 10, or 15 (Kitzing).
12–13	54.4	5 (Kitzing).
7–8	52	5, 10, or 15 (except 15 minutes in Kitzing).
7–8	54	5 or 10 (except 10 minutes in Kitzing).
7–8	56	5 (except in Kitzing).
4–6	52	5, 10, or 15.
4–6	54	5 or 10 (except Kitzing), and 15 in Oderbrucker.
4–6	56	5 (except Kitzing).
No soaking.	57	5, 10, or 15.
Do	58	5 or 10.

TABLE VI.—*Effect on the germination of three six-rowed varieties of barley, etc.*—Continued.

ARRANGED ACCORDING TO DURATION OF TREATMENT.

(O, Oderbrucker; M, Mansury; K, Kitzing.)

Period of soaking in hot water.	Duration of hot-water treatment.	Temperature of hot water (maximum).	Germination.
Hours.	*Minutes.*	°*C.*	*Per cent.*
12-13	15	52	K-88.
12-13	10	52	K-97.
12-13	5	54	K-70.
7-8	15	52	O-92, M-86, K-48.
7-8	10	54	O-77, M-82, K-14.
7-8	5	56	O-85, M-71, K-15.
4-6	15	54	O-72, M-52, K-25.
4-6	15	52	O-90, M-98, K-68.
4-6	10	54	O-92, M-97, K-54.
4-6	5	56	O-84, M-71, K-24.
No soaking	15	57	O-98, M-99.
Do	10	58*	O-96, M-96.
Do	5	58*	O-95, M-97.

* Probably not the extreme limit; no higher temperature was tried.

All of the seed used was good fresh seed of the 1905 and 1906 crops, with the possible exception of the Kitzing barley, which, although the control gave 96 per cent of germination, looked old and badly weathered. The inability of the Kitzing barley to endure as severe treatments as the other barleys may have been due to this fact. In general, therefore, the treatments mentioned were accepted as the maximum in severity which would prove at all practicable.

Experiments were then undertaken based on the results recorded in Tables V and VI. These experiments with Jensen's modified hot-water treatment are shown in Tables VII to XII, inclusive. The treatment in each case is designated by three figures—e. g., 5-5-56—in which the first figure gives the number of hours of soaking in cold water, the second the number of minutes of soaking in hot water, and the third the temperature of the hot water in degrees centigrade. Treatment 5-5-56 is therefore a five-hour soaking in cold water, followed by a five-minute soaking in hot water at 56° C. Since small quantities of seed were used, a draining of only a few minutes was deemed necessary. The amount of seed was so small compared with the bulk of hot water that the temperature of the latter was seldom affected even slightly. The actual duration of soaking in some cases varied slightly from that given in the tables, but never to the extent of one hour's difference (except where noted). These variations, amounting mostly to fifteen and twenty minutes, are without doubt negligible. The duration of the hot-water treatments is in every case correct within a few seconds.

The temperature record (except when otherwise noted) is correct within 0.5° C. In all tests and treatments the centigrade scale has been used. In many cases the temperature was held absolutely constant throughout the treatment. As the tests were made for the most part at intervals of 2 degrees, the slight variations of less than 0.5° C. are likewise negligible, especially when the practical application of the results is considered. The laboratory germination tests (made by W. L. Goss in the Seed Laboratory of the Bureau of Plant Industry) are given in percentages. The field germination in most cases is estimated as excellent (E), good (G), fair (F), poor (P), or very poor (VP). In Table X the field germination is accurately computed and given in percentages.

Some seed was treated at Washington, D. C., during the winter or early spring months and kept thoroughly dry after treatment until it was planted at St. Anthony Park, Minn. Other seed was treated at St. Anthony Park just before planting and was not allowed to dry completely before seeding, which usually took place on the same or the following day. In 1907 the seeding was interrupted by snowstorms, and the treated seed was then kept moist and cool for several days in a tin box, which was packed in sawdust in an icehouse, so that no germination took place before seeding. The varieties used were those which had shown large amounts of smut at the Minnesota Agricultural Experiment Station in previous years. No actual counting tests of the amounts of smut had previously been made, and when such tests were made in 1907 the standards of percentages used in the Minnesota station's previous records were found to be too high, so that they could be used only in general comparisons. Particulars as to the dates of planting, the germination in the field, and the details of smut pickings have been omitted from the tables. The seeds were in all cases planted at the usual time for these grains at St. Anthony Park.

HOT-WATER TREATMENT OF BARLEY.

The results of the experiments with barley in 1907 are recorded in Table VII. The barleys used were Minnesota Nos. 142, 144, and 145. In 1906 No. 142 contained the most smut; Nos. 144 and 145 were affected about equally and had considerably less than No. 142. In 1907 field plats of No. 142, according to careful estimates, contained 4.62 per cent of smut.

TABLE VII.—*Results of experiments with Jensen's modified hot-water treatment on barley, at Washington, D. C., and at St. Anthony Park, Minn., 1907.*

Treatment.	Minnesota No. 142.*				Minnesota No. 144.*				Minnesota No. 145.*				Minnesota No. 142.†			
	Germination in laboratory.	Germination in field.	Number of heads.	Smut.	Germination in laboratory.	Germination in field.	Number of heads.	Smut.	Germination in laboratory.	Germination in field.	Number of heads.	Smut.	Germination in laboratory.	Germination in field.	Number of heads.	Smut.
				P. ct.				*P. ct.*				*P. ct.*				*P. ct.*
Control	97	E	332	6.95	94	E	512	0.78	98	E	486	7.40	97	E	1,801	3.65
0-10-58	93	E	469	5.75	91	E	360	1.94	90	E	495	6.87	.....	E	1,298	4.77
0-15-56	93	E	444	7.20	92	E	494	0	96	E	668	9.28	.....	E	1,517	3.75
5-5-56	94	F	323	2.47	86	F	259	.38	96	F	462	.43	.....	G	844	.14
5-10-54	96	F	426	.93	92	F	292	.34	92	E	274	0	.....	E	1,295	.07
5-15-52	90	E	467	0	88	E	357	0	96	E	823	0	.....	E	1,337	.07
7-5-54	92	E	412	0	72	E	295	0	93	E	507	0	.....	E	1,279	0
7-10-54	52	F	205	0	62	F	174	0	90	G	421	0	.....	G	992	0
7-15-52	87	G	303	0	78	G	280	0	94	G	366	0	.....	E	1,186	0
12-5-54	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	E	1,204	0
12-10-54	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	F	568	0
12-15-52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	E	1,178	0
15-5-54	63	P	230	0	74	P	172	0	88	P	351	0	.....	.....	.....	.....
15-10-54	12	VP	77	0	12	VP	34	0	56	VP	274	0	.....	.....	.....	.....
15-15-52	60	P	458	0	72	P	136	0	88	F	344	0	.....	.....	.....	.....
24-5-54	.....	P	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	F	861	0
24-10-52	.....	F	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	G	1,262	0
24-15-52	.....	P	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	G	1,091	0

* Treated at Washington, D. C., March 15, 1907.

† Treated at St. Anthony Park, Minn., about May 4, 1907, before sowing, but thoroughly dried before planting.

The control and the "no-soak" treatment gave plants which matured two to three days earlier than any of the other treatments. Soaking more than twelve hours, even when followed by mild treatments (ten to fifteen minutes at 52° C.), impaired germination decidedly.

Temperatures above 54° C., e. g., 56° C. for five minutes, did not prevent all of the smut but impaired germination both in the dried and freshly treated seeds. The indicated treatment lies therefore in a previous soaking of between four and twelve hours, a hot-water treatment of from five to fifteen minutes, and temperatures of 52° to 54° C. A treatment of more than five minutes at 54° C., after soaking from seven to twelve hours, injured germination in most cases.

The most successful treatment, both in the prevention of smut and in unimpaired germination, was a soaking of from five to seven hours in cold water followed by a fifteen-minute soak in hot water at 52° C. An even longer soak, e. g., twelve hours, did no damage to germination in freshly treated seed.

Drying after treatment was apparently not injurious to the smut-preventing power of the treatment and did not seriously affect the germination.

Extensive experiments similar to those recorded in 1907 were undertaken in 1908 to test these results. Unfortunately the barley used (Minnesota No. 195), though recorded as having considerable smut in 1907, produced almost no smut in 1908, the control giving no smut. The results were therefore useful only in connection with the data on germination, and these were in accord with those shown in Table VII. Experiments in regard to germination after the various treatments made with Boehme's white-bearded hull-less barley (G. I. No. 533) gave similar results throughout.

The success of Jensen's method lies without doubt in the soaking in cold water. Soaked seed probably allows a more uniform conduction of heat through the embryo than dry seed. There is, however, another effect which is, perhaps, of even greater importance. Soaking may stimulate to activity the contained smut mycelium. It seems possible, therefore, that Jensen's treatment on the one hand is efficient merely because of the increased conductivity brought about by soaking and on the other because it stimulates the mycelium to growth, in which condition it is more easily injured by the hot-water treatment. In order to throw light on this point, and also to devise, if possible, a method less injurious to the seed than Jensen's treatment the following experiment was undertaken in 1908: Some barley was soaked in ice water at a temperature of 3° C., and some in cold water at ordinary temperatures, viz, 20° C., for comparison. The results are recorded in Table VIII.

TABLE VIII.—*Results of experiments with Jensen's modified hot-water treatment on barley (Minnesota No. 142), St. Anthony Park, Minn., 1908.*

Treatment.	Seed soaked in ice water (3° C.).			Seed soaked in cold water (20° C.).		
	Germination in field.	Number of heads.	Smut.	Germination in field.	Number of heads.	Smut.
			Per cent.			*Per cent.*
Control	E	1,453	2.0	E	1,453	2
6-5-52	E	976	2.5	E	*1,000	0
6-10-52	E	996	2.2	E	*1,000	0
6-15-52	E	941	1.0	E	*1,000	0
6-5-54	E	1,115	.9	E	*1,000	0
6-10-54	E	844	1.3	F	†1,000	0
6-15-54	....	....	....	VP	†1,000	0
6-5-56	E	839	1.3	VP	†1,000	0
6-10-56	P	671	.4	0	....	....
6-15-56	VP	....	....	0	....	....
6-5-58	VP	521	.7	0	....	....

* Approximate figures. † Less than 1,000.

The cold-water soaking treatments confirm those of 1907 in regard to smut prevention and germination. The ice-water soaking, however, is seen to be entirely inefficient against the smut and therefore valueless. This is probably best explained by the inability of the low-temperature soaking to stimulate the dormant fungous mycelium to any considerable growth. If this is true, the temperatures which after the cold-water soaking are sufficient to kill the growing mycelium without seriously affecting the germinating embryo have little or no effect upon the almost dormant mycelium after the ice-water soaking. A similar explanation might also be given for the inability of the hot-water treatment without any previous soaking (see Table VII) to prevent smut. In the experiments on wheat (Table X), ice-water soakings for twelve and thirteen hours were efficient in smut prevention, as were also soakings of six hours followed by temperatures of 56° C. or more, but in the latter case germination was seriously impaired by most of the treatments. These facts suggest, furthermore, that the soakings in ice water for six hours stimulate the mycelium, but to such a slight degree that it requires high and injurious temperatures (56° C.) to destroy the smut in its almost dormant stage.

HOT-WATER TREATMENT OF WHEAT.

The results of experiments with wheat are presented in Table IX (1907) and Table X (1908). A bearded, hard spring wheat (Minnesota No. 188) was used in all the experiments. This variety developed considerable smut in 1906. In 1907 counts made in the fields showed in general 3 to 4 per cent of smut, and in 1908 similar counts showed as much as 5 per cent.

TABLE IX.—*Results of experiments with Jensen's modified hot-water treatment on wheat (Minnesota No. 188), St. Anthony Park, Minn., 1907.*

Treatment.	Planted soon after treatment.			Seed dried after treatment.		
	Germination in field.	Number of heads.	Smut.	Germination in field.	Number of heads.	Smut.
			Per cent.			*Per cent.*
Control	....	2,856	1.29	....	2,856	1.29
0-10-58	E	2,060	1.35	G	1,752	2.16
0-15-58	G	1,793	1.72	F	1,596	1.25
5-5-56	E	2,357	0	E	2,309	0
5-10-54	E	2,450	0	E	1,856	0
5-15-54	E	1,841	0	E	1,716	0
7-5-56	E	2,160	0	E	1,414	0
7-10-54	E	2,306	0	E	2,102	0
7-15-54	E	1,873	0	E	1,767	0
13-5-54	E	2,454	0	E	1,998	*0
13-10-52	E	2,416	0	E	2,383	*0
13-15-52	E	2,444	0	E	2,050	*0
24-5-54	G	1,392	0	F	1,164	.08
24-10-52	G	1,661	0	F	1,422	.14
24-15-52	F	1,517	0	F	554	0

* Soaked in cold water for twelve hours.

TABLE X.—*Results of experiments with Jensen's modified hot-water treatment on wheat (Minnesota No. 188) at Washington, D. C., and St. Anthony Park, Minn., 1908.*

Treatment.	Seed soaked in ice water (0.6°–1.5° C.).*				Seed soaked in cold water (15° C.–17° C.).*				Seed soaked in ice water (3° C.).†			Seed soaked in cold water (20° C.).†		
	Germination in laboratory.	Germination in field.	Number of plants.	Smut.	Germination in laboratory.	Germination in field.	Number of plants.	Smut.	Germination in field.	Number of heads.	Smut.	Germination in field.	Number of heads.	Smut.
	P. ct.	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*		*P. ct.*
Control	92.5	68	135	2.96	92.5	68	135	2.96	E	1,257	4.6	E	1,257	4.6
5-5-52	93.0	80	159	3.12	94.5	81	162	.61	E	1,771	2.9	E	1,567	.1
5-10-52	92.0	82	163	2.45	95.0	85	169	0	E	1,383	3.1	E	1,200+	0
5-15-52	94.5	79	158	3.16	95.0	79	158	0	E	1,572	3.2	E	1,200+	0
5-5-54	91.0	83	166	3.01	93.0	82	163	0	E	1,587	1.2	E	1,200+	0
5-10-54	85.5	73	145	2.75	92.5	75	150	0	E	1,368	.8	E	1,200+	0
5-15-54	80.5	71	141	.70	80.0	66	131	0	E	1,401	.3	G	1,200+	0
6-5-56	92.5	74	147	2.72	81.5	66	132	0	E	1,298	.3	G	1,000−	0
6-10-56**	71.5	70	139	.71	30.0	40	80	0	G	1,405	.4	VP	1,000−	0
6-15-56	36.5	50	99	0	3.0	7	13	0	F	794	0	VP	......	......
6-5-58	61.0	50	100	0	2.5	......	......	......	P	1,040	1.0	0	......	......
6-10-58	8.5	13	25	0	0	......	......	......	......	......	......	......	......	......
6-15-58	1.0	0	......	......	0	......	......	......	......	......	......	......	......	......
12-5-52††	91.0	81	162	1.85	92.5	82	163	0	......	......	......	......	......	......
12-10-52	96.5	80	160	1.25	89.5	79	158	0	......	......	......	......	......	......
12-15-52	87.5	78	155	0	88.5	74	147	0	......	......	......	......	......	......
12-5-54	89.0	80	160	0	89.5	69	138	0	......	......	......	......	......	......
12-10-54	82.5	74	148	0	80.5	58	116	0	......	......	......	......	......	......
12-15-54	77.5	66	131	0	72.0	49	98	0	......	......	......	......	......	......
13-5-56	73.5	51	101	0	65.0	22	44	0	......	......	......	......	......	......
13-10-56	15.0	32	63	0	0	......	......	......	......	......	......	......	......	......
13-15-56	1.0	7	13	0	0	......	......	......	......	......	......	......	......	......
13-5-58	4.5	......	......	......	0	......	......	......	......	......	......	......	......	......
13-10-58	0	......	......	......	0	......	......	......	......	......	......	......	......	......
13-15-58	0	......	......	......	0	......	......	......	......	......	......	......	......	......

* Treated at Washington, D. C., January 29, 1908; planted at St. Anthony Park, Minn., April 15 and 16, 1908.

† Treated at St. Anthony Park April 17, 1908; planted at St. Anthony Park April 18, 1908.

** Average, 55.4° C.

†† 51°–51.4° C.

The results of the treatments shown in Tables IX and X are seen to be similar to those with barley. Wheat, however, shows ability to endure longer soaking and slightly higher temperatures. Treatments of ten minutes at 54° C., even after a soaking of twelve hours, gave good results both in germination and smut prevention.

The most desirable treatment is apparently the following: Soaking for five to seven hours in cold water followed by immersion in hot water at 54° C. for ten minutes.

The ice-water treatments likewise gave results similar to those of barley—i. e., they were inefficient against the smut except at high temperatures injurious to germination.

EFFECT ON GERMINATION OF DRYING TREATED SEED.

In the experiments of 1908 with both wheat and barley, data on the effect of the drying of the treated seed on germination were obtained. Part of the seed was treated January 29, and tests for germination were made in the Seed Laboratory on the following dates: January 31, February 6 and 20, and March 5 and 19. The remainder of the seed was treated February 4, 1908, and laboratory tests were made February 3, 13, and 20, and March 5 and 19. The seed was planted April 16. The tests were made from seed from both ice-water and cold-water soakings followed by the hot-water treatments. The results with both barley and wheat and from both treatments were similar. In all treatments which were not injurious to germination the tests at the different dates gave practically the same results (fig. 2, curves B and F). Where the treatment was injurious, however, the germination tests on different dates showed in general an improvement in vitality as the length of time after treatment increased, giving on the average the highest germination percentages on the last date, March 19 (curves C, D, G, and H). These relatively high percentages were sustained in the field germination tests, though all of the treated as well as all of the control seed, after having been kept dry, gave field germination tests uniformly lower than in the Seed Laboratory tests. This fact, as shown by the controls, was probably

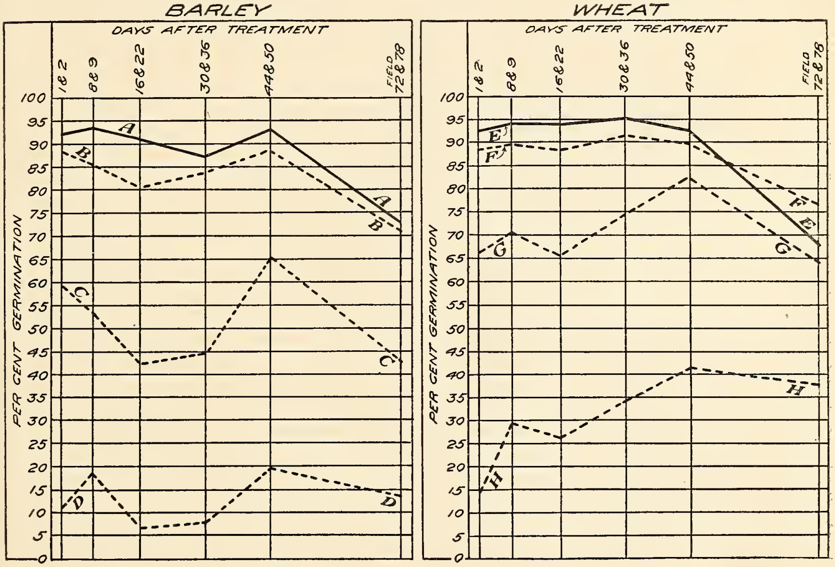

FIG. 2.—Diagram showing the effect on germination of drying the seed of barley (Minnesota No. 195) and wheat (Minnesota No. 188) after the application of Jensen's modified hot-water treatment for loose smut. The treatments were made January 29 and February 4, 1908, at Washington, D. C. The germination tests were made the number of days indicated after treatment. The first figures (1, 8, 16, etc.) give the dates after the treatment of February 4; the second figures (2, 9, 22, etc.), dates after that of January 29. The seed was planted at St. Anthony Park, Minn., April 16, 1908. *A*, barley, control (no treatment); *B*, barley, average of 19 tests, initial test between 100 and 76 per cent, inclusive; *C*, barley, average of 6 tests, initial test between 75 and 51 per cent, inclusive; *D*, barley, average of 11 tests, initial test less than 51 per cent; *E*, wheat, control (no treatment); *F*, wheat, average of 20 tests, initial test between 100 and 76 per cent, inclusive; *G*, wheat, average of 5 tests, initial test between 75 and 51 per cent, inclusive; *H*, wheat, average of 11 tests, initial test less than 51 per cent.

due to field conditions. In some cases wheat which immediately after treatment, January 31, showed no germination, on March 19 showed 30 per cent and in the field 40 per cent. The results indicate that after the drying of the seeds after treatment a delay of one to two months not only does not injure but improves the germination where seeds have been severely treated. The detailed results of these tests are shown in Tables XIII and XIV, inclusive.

EFFECT OF JENSEN'S MODIFIED HOT-WATER TREATMENT ON THE YIELD OF GRAIN.

The percentages of germination in the foregoing tables indicate that from many of the treatments a decreased yield must result unless allowance is made in planting for injury to the seed. Those treatments selected as the best for barley (5–15–52) and wheat (5–10–54) cause little or no injury to germination. Swingle's method for wheat showed that successful treatment for loose smut of wheat was accompanied by a loss of as much as 25 per cent of the seed. Results of experiments to determine the effect of the treatments on yield are shown in Table XI. Plats of one-twentieth acre at St. Anthony Park, Minn., and of one-tenth acre at McPherson, Kans., were planted in each case. These plats were close together on a uniform soil, thus giving an accurate basis for comparison. In seeding no allowance was made for injury to seed germination. In general the stand on the treated plats appeared less uniform and slightly poorer than on the control plats. The yields were tested in a manner similar to that used for the testing of varieties at these stations.

In estimating the amounts of smut in fields which were too large to permit a count of all the heads or plants the following method, proposed by Mr. H. J. C. Umberger, has been found useful and accurate and has been adopted throughout. In this method a point is selected at random in one of the drill rows, and starting from this point in the row 100 heads are counted. A hand counting register is very useful in this work. Another starting point is then selected in a different row at some distance from the first and another 100 heads are counted. This is continued over the entire plat usually until the sum of a thousand heads is reached. The exact number of counts is determined by the size of the plat and the desire for accuracy. The greater the number of counts the more accurate is the result. In some cases only 600 heads were counted, in which case some of the plats were again checked up. At other times as many as 2,000 heads were counted in each plat. This method of estimating the prevalence of smut has some advantage over the hoop or square measure methods, especially in speed, and is even more accurate than these methods, by reason of the fact that the number of heads really expresses comparatively the number of plants, which is not always the case when other methods are followed.

TABLE XI.—*Results of experiments with Jensen's modified hot-water treatment on wheat and barley, showing the effect on yield of grain.*

ST. ANTHONY PARK, MINN., 1908.

Treatment.	Barley.			
	Minnesota No. 105.		Minnesota No. 195.	
	Smut.	Yield per acre.	Smut.	Yield per acre.
	Per cent.	*Bushels.*	*Per cent.*	*Bushels.*
Control	2	37	1.4	40.0
5-15-52*	Trace.	37	0	42.2
Ice 5-15-52	0.1	33.9	.1	33.7
	Wheat: Minnesota No. 188.			
Control	3.9	24.3	6+	22.3
5-10-54	† Trace.	**20.6	Trace.	**21.6
Ice 5-10-54	4.2	20	3	††20.3

McPHERSON, KANS., 1908.

Treatment.	Spring wheat: Kubanka No. 2094.		
	Smut.	Yield per acre.	Remarks.
	Per cent.	*Bushels.*	
Control	0.25	13.46	
8-15-54	0	11.63	Temperature varied from 53.5-54° C.; 54° C. most of time.
Ice 8-15-54	Trace.	12.42	Temperature varied from 53.5-54° C.; 54° C. most of time.
	Barley: Caucasian No. 90.		
Control	1.25	35.83	
6-15-51.5	0	26.15	Temperature varied from 51°-51.5° C.; 51.5° C. most of time.
Ice 6-15-51.5	0	29.48	Temperature varied from 51°-51.5° C.; 51.5° C. most of time.

* For Minnesota No. 195, soaked 6 hours 20 minutes.
† Five heads found in whole plat.
** Temperature varied from 52.8° to 54° C.; 53.8° C. most of time.
†† Temperature varied from 54° to 53.2° C.; 53.4° C. most of time.

The uneven stand of the treated grain has already been noted. The cold-water soakings gave uniformly excellent results in the prevention of smut, leaving in no case more than a trace. This trace amounted to five heads or less in the whole plat, found by very careful search. In barley, Minnesota No. 195, not a smutted head was seen. The control in this case, however, had very little smut (1.4 per cent). The ice-water soakings were less successful, especially in wheat, where in one plat the treated grain had 4.2 per cent against

3.9 per cent in the control. These results confirm those shown in the previous table.

The yield at St. Anthony Park was slightly decreased by the treatment after cold-water soakings, while at McPherson it was quite seriously affected. In Minnesota barley it was practically equal to the control plat (exceeding it in Minnesota No. 195). In wheat there was a decrease in all cases, amounting to 15 per cent in one plat. Treatment after ice-water soakings invariably resulted in a loss in yield amounting in Minnesota No. 195 barley to 20 per cent. The ice-water treatments should, therefore, be discarded as undesirable in all respects.

Treatment after cold-water soakings, on the other hand, was successful in the prevention of smut, although a loss in yield was evident in most cases.

TEST OF THE JENSEN MODIFIED HOT-WATER TREATMENT ON A LARGE SCALE.

An attempt was made in 1907 and 1908 to test the Jensen hot-water treatment under the difficulties present at an experiment station where larger fields and more of them were planted than were found necessary in the previously described experiments. This work was conducted by Mr. H. J. C. Umberger, at McPherson, Kans., on the cooperative experiment station of the Office of Grain Investigations. There had been considerable smut at the station in 1906 in both wheat and barley, and an accurate estimate of the amount in most of the varieties in large plats was made in 1907. It was proposed to clean the entire place of smut in one year. All wheats and barleys on the station, with the exception of the hybrids, were treated in the fall of 1907. The hybrids, on account of a possible loss of seed, which could not be replaced, were left untreated.

The apparatus used in treatments was a 40-gallon galvanized-iron tub and a 2-burner gasoline stove. This and all other material necessary could easily be duplicated on an ordinary farm. The following treatments were employed: For wheat, 7–15–54, and for barley, 6–15–52. The conditions at the experiment station were, of course, even more difficult than on an ordinary farm, on account of the large number of varieties which it was necessary to handle. All treated seed was dried after treatment for at least a week previous to sowing.

The station farm comprised about 30 acres, fully one-half of which was in wheat and barley. There were 59 plats of wheat and barley of one-tenth and one-twentieth acre each, the majority being one-tenth-acre plats. An accurate smut record of 45 of the 59 plats was kept in 1907, while of the remaining 14 no record was taken, though probably smut was present. The smut varied from a trace on some plats to a maximum of 7.3 per cent on others, the average of the plats being 2.1 per cent. All computations were made by Mr. Umberger according to the method previously described. In addition to the large plats, 550 varieties and selections, comprising about 2,000 rows, were individually treated. One man's time, nine hours a day for about two weeks, was consumed in this work. It was estimated that 40 lots of seed for as many one-tenth-acre plats were treated in five hours. This rate can be considerably increased with larger tubs and more heat and where only one or two varieties are handled, as under ordinary farm conditions.

The results of these treatments became evident in 1908. Not a head of smut could be found on the whole farm among the barley and common wheats (*Triticum vulgare*). A few varieties of durum wheats, however, had an occasional smutted head, constituting an exceedingly small fraction of 1 per cent. This probably indicates that durum wheats require a slightly more severe treatment than common wheats. The untreated hybrids, which, as previously stated, were the only untreated plants on the farm, contained 2 per cent of smut in 1908. This is the only check on the amount of smut at the station for the year. Conservatively estimated, it represents the percentage of smut eliminated by the treatment. The injury to germination caused by treatment was variable. It was not more than 25 per cent in any case where the seed was properly dried and kept dry, and probably on the average was less than 15 per cent under such conditions.

As shown by other experiments noted in this bulletin, the amount of time given to the drying of treated seed was undoubtedly unfavorable to germination. The seed might better have been planted immediately or allowed to rest for one to two months. It should also be pointed out that the injury to germination did not necessarily mean a commensurate decrease in yield. It seems probable that the yield was not affected to the extent shown by the decrease in germination, since the fewer plants had greater opportunities for stooling. This attempt to clean the farm of smut in one year was without question successful and demonstrated the possibility of using this method on a fairly large scale.

Mr. A. H. Leidigh, of Hutchinson, Kans., successfully used the modified hot-water treatment on his farm in 1907–8. In a letter to the Office of Grain Investigations, he says:

> During vacation last fall I treated some Tennessee winter barley (from McPherson station) for loose smut as per specific directions from Mr. Umberger, of your office. This was for a farm field of barley; the work was done with ordinary farm equipment. I take pleasure in telling you that the modified hot-water treatment as used is a success. As the loose smut is increasing rapidly and is not to be controlled by ordinary methods, I consider our results of great importance.

ROGUING TREATMENT FOR THE PREVENTION OF LOOSE SMUTS OF WHEAT AND BARLEY.

Maddox[a] found that by carefully picking out all smutted heads in small plats seed almost free of smut was obtained in two years. Experiments were undertaken in 1907 at St. Anthony Park to test this method and to determine its practical possibilities. The results are shown in Table XII.

TABLE XII.—*Results of experiments in the prevention of loose smuts of wheat and barley by roguing the smut, St. Anthony Park, Minn., 1907 and 1908.*

BARLEY.

Plat.	Variety.	1907.		1908.
		Treatment.	Smut.	Smut.
			Per cent.	*Per cent.*
C	Minnesota No. 105	Control; no treatment	*1.69	2.0
A	......do	Rogued	1.69	.2
B	......do	Formalin; rogued	1.16	.5
E	Minnesota No. 142	Control; no treatment	*4.62	2.0
D	......do	Formalin; rogued	4.62	1.0
		WHEAT.		
F	Minnesota No. 188	Control	3 to 4	5.0
T	......do	Formalin; rogued	.2	.5
S	......do	......do	4.0	.1

* Percentage from rogued plats.

Five plats (one-fortieth of an acre each) were laid off for the barley work. Three of these (A, B, and C) were sown to barley, Minnesota No. 105, and two (D and E) to Minnesota No. 142. Both barleys contained considerable smut in 1906. Plats C and E were control plats and were not treated. In plats B and D the seed before planting was immersed for two hours in a formalin solution (1 pound of formalin to 45 gallons of water) in order to test the efficiency of this treatment for both loose and covered smut. In these plats, as well as in plat A (which was not treated with formalin), all of the smut was picked every day. By frequent roguing it was hoped to get the smut heads before they had a chance to distribute their spores. The details of the pickings are shown graphically in figure 1, p. 16.

The five plats of barley were grown together in a row in order to test the roguing method under fairly adverse conditions. Roguing was very thoroughly carried out, and in the three plats pickings were made daily from July 2 to harvest (July 29). The time spent in roguing averaged approximately fifty hours per plat, an amount of time hardly allowable in farm practice. The test shows, however, the possibilities of the method even under the adverse conditions brought about by the close proximity of plats C and E to the rogued plats. In plats C and E the smut was allowed to be distributed in a natural manner and undoubtedly caused infection in adjacent plats. The nearest large barley fields were 600 feet to the west of these experimental plats. The percentage of smut in 1907 was 1.69 in Minnesota No. 105 and 4.62 in Minnesota No. 142 in the rogued plats (A and D). These were accepted for the controls, since the seed used in plats C and E was from the same bulk as the seed for A and D, respectively. In plat B (Minnesota No. 105) 1.16 per cent of smut was present. The seed obtained from these plats was planted in twentieth acres in 1908. The controls (C and E) were planted in the barley variety series, while the seed from the rogued plats A, B, and D was planted among the oat varieties remote from any barley fields. The smut in each plat was computed as previously described in connection with Table XI. The results show a decided decrease in smut in every rogued plat from that recorded for 1907. The decrease would undoubtedly have been greater if the rogued plats had been completely isolated the previous year (see Table XII, plat S). The results obtained indicate clearly that the smut can be greatly reduced by roguing the smutted heads as soon as they appear. It is almost certain, however, that this method would not prove practicable in farm practice on account of the time necessary to rogue even a small plat. It could be used only in connection with a seed-plat system.

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[a] Maddox, F. Loc. cit.

Results similar to those obtained with barley were obtained with the loose smut of wheat. Minnesota No. 188, a bearded hard spring wheat, was used. Plats F and S were from the same bulk of seed. Plat T was from a different lot of seed, and no control was planted. T and S were one-tenth-acre plats both in 1907 and 1908, while control F was a large field at the station. Plat S was isolated among the barley varieties in 1907, while plat T was sown among the wheat varieties, with a plat of Minnesota No. 188 on one side and Preston wheat on the other. It was hoped that plat T would give a test of the roguing under unfavorable conditions, similar to the barley tests described above, but the amount of smut in 1907 was only 0.2 per cent as compared with 4 per cent in plat S and 3 to 4 per cent in the large fields. This small amount of smut makes the results in plat T of comparatively little value as a test for the roguing method. Plat S, however, shows conclusively the possibilities of the method when the rogued plat is isolated, since the decrease from 4 per cent in 1907 to 0.1 per cent in 1908 stands out in sharp contrast to the results in the large field controls, viz, 3 to 4 per cent in 1907 and 5 per cent in 1908.

The above experiments show that picking out the loose smut heads in both wheat and barley will decrease the amount of smut in the following crop. The best results are obtained by isolation of the plat (see Table XII, plat S), but a decrease is obtained even without isolation when the picking is carefully done. The roguing can be facilitated by pulling out the entire plant whenever a smut head appears. This will avoid the necessity of picking out several other smut heads later in the season. Planting the grain in rows 10 to 12 inches apart in order to allow walking between the rows also aids the roguing process.

The necessity for isolation is well shown in another series of experiments. From the treatment tests with Jensen's method made in 1907, Table VII, eight lots of seed of Minnesota barley No. 142 (1907 controls contained 6.9 per cent of smut), from which the smut had been entirely eradicated by the hot-water treatment, were selected. Since the treated grain had been sown in contiguous plats, the successfully treated rows during the season of 1907 were subject to inoculation by spores from the unsuccessfully treated and control plats which were usually less than a rod away. This seed from the smut-free rows when planted in 1908 gave in every case loose smut varying from 0.16 per cent to 2.4 per cent. The latter amount was equal to the untreated control of 1908, in Table XII, and shows an infection equal to that in nontreated seed. The same number of lots of wheat (Minnesota No. 188) was selected from successfully treated seed (Table IX) in 1907 under conditions similar to those described for barley. The results were in general the same. Although the seed came from rows with no smut in 1907, every lot contained smut varying from 0.1 per cent to 0.5 per cent in 1908. The increase in the smut was not as marked as in the barley, since the field control of the same wheat in 1908 had 5 per cent of smut, but in no case did the seed remain free from smut. Isolation is therefore very necessary to the maintenance of freedom from loose smut in both wheat and barley.

Just how far removed from a smutted field a plat must be in order to prevent infection entirely can not be definitely stated at this time, as no experiments have been performed to determine this point. Evidence presented in this bulletin indicates, however, that sufficient isolation of a seed plat can be obtained on an ordinary farm to avoid any considerable infection, and the maintenance of such a plat will soon reduce the smut on the farm to a mere trace and will ultimately eradicate it. Wind-borne spores travel long distances, but the possibilities of infection decrease very rapidly with the increase of the distance of the seed plat from the smutted fields. An intervening grove or strip of wood between the seed plat and the smutted field is a very valuable protection.

In connection with the above-described treatments of barley for loose smut, tests made with the covered smut showed that the latter can be easily and completely destroyed by the hot-water treatments, such as 5–15–52, or by immersion in a solution of 1 pound of formalin to 45 gallons of water for two hours. Undoubtedly other treatments, such as are efficient for the bunt of wheat and the loose smut of oats, would also be useful against this smut. The roguing method carried on in connection with loose smut (see fig. 1 and Table XII) was fairly successful against covered smut in one case (Minnesota No. 105, Table XII, plat A). In another case (Minnesota No. 142, Table XII, plat C), where no covered smut appeared in the rogued plat in 1907, 1 per cent was present in 1908. The simplicity and efficiency of the formalin treatment make the practical consideration of the roguing method for the covered smut entirely unnecessary.

TABLE XIII.—*Effect on germination of drying the seed of barley after the application of Jensen's modified hot-water treatment, Washington, D. C., and St. Anthony Park, Minn., 1908.*

Treatment.	Date of treatment.	Germination tests of Seed Laboratory.					Germination in field, planted April 16.
		January 31.	February 6.	February 20.	March 5.	March 19.	
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Control	....	92.0	93.5	91.0	87.0	93.0	73.0
Ice 5–5–52	Jan. 29	93.0	95.5	92.0	91.5	92.0	79.0
Ice 5–10–52	...do.....	87.5	88.0	89.0	87.0	88.0	80.0
Ice 5–15–52	...do.....	85.5	92.0	89.5	89.0	92.5	82.0
Ice 5–5–54	...do.....	90.0	90.5	87.0	85.5	91.5	73.0
Ice 5–10–54	...do.....	85.5	83.5	72.0	80.0	87.0	70.0
Ice 5–15–54	...do.....	58.5	60.5	48.0	47.5	72.0	45.0
Ice 5–5–56	...do.....	70.0	77.5	70.5	62.5	80.0	65.0
Ice 5–10–56	...do.....	23.0	43.5	16.0	15.0	37.5	34.0
Ice 5–15–56	...do.....	5.5	7.0	3.0	2.5	20.0	17.0
Ice 5–5–58	...do.....	12.0	....	11.5	....	25.0	18.0
Ice 5–10–58	...do.....	1.5	....	5.0	....	3.5	2.0
Ice 5–15–58	...do.....	1.0	....	0	....	1.5	2.5
5–5–52	...do.....	95.5	96.5	95.5	95.0	95.5	87.0
5–10–52	...do.....	94.0	94.0	93.0	90.0	91.5	76.0
5–15–52	...do.....	92.0	94.0	94.0	92.0	93.5	77.0
5–5–54	...do.....	94.0	92.5	91.0	91.5	93.5	73.0
5–10–54	...do.....	80.5	79.5	79.5	81.0	85.0	63.0
5–15–54	...do.....	48.5	41.5	35.5	42.5	65.5	39.0
5–5–56	...do.....	11.5	37.0	21.5	17.0	46.5	33.0
Ice 13–5–52	Feb. 4	89.0	....	91.0	90.5	95.0	75.0
Ice 13–10–52	...do.....	89.5	77.0	79.0	86.0	88.0	77.0
Ice 13–15–52	...do.....	84.5	84.5	76.5	73.5	77.5	60.0
Ice 13–5–54	...do.....	87.0	93.0	85.0	81.0	89.5	76.0
Ice 13–10–54	...do.....	76.5	73.0	58.0	53.5	79.0	56.0
Ice 13–15–54	...do.....	51.5	37.0	29.5	37.5	58.0	38.0
Ice 13–5–56	...do.....	73.5	73.5	58.5	56.0	75.0	49.0
Ice 13–10–56	...do.....	22.0	24.0	10.5	12.0	31.5	20.0
Ice 13–15–56	...do.....	2.5	4.0	1.0	1.0	3.0	2.0
Ice 13–5–58	...do.....	4.5	0	5.0	0	6.5	5.0
13–5–52	...do.....	95.5	....	82.0	....	92.0	75.0
13–10–52	...do.....	92.5	....	70.5	....	88.5	60.0
13–15–52	...do.....	84.5	63.0	31.5	....	76.0	44.0
13–5–54	...do.....	89.5	89.0	75.5	74.0	86.0	68.0
13–10–54	...do.....	56.5	32.0	10.5	20.5	40.0	24.0
13–15–54	...do.....	4.5	9.0	2.5	3.5	13.5	3.0
13–5–56	...do.....	28.5	26.0	5.5	12.5	30.0	13.0

TABLE XIV.—*Effect on germination of drying the seed of wheat after the application of Jensen's modified hot-water treatment, Washington, D. C., and St. Anthony Park, Minn., 1908.*

Treatment.	Date of treatment.	Germination tests of Seed Laboratory.					Germination in field, planted April 16.
		January 31.	February 6.	February 20.	March 5.	March 19.	
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Control		92.5	94.0	94.0	95.0	92.5	68
Ice 5-5-51.5	Jan. 29	91.0	93.5	94.5	95.0	93.0	80
Ice 5-10-51.5	do	90.5	91.0	91.0	95.0	92.0	82
Ice 5-15-51.5	do	85.5	90.5	89.5	93.0	94.5	79
Ice 5-5-53.5	do	87.5	89.5	92.0	94.5	91.0	83
Ice 5-10-53.5	do	75.5	91.5	83.0	91.5	85.5	73
Ice 5-15-53.5	do	53.5	76.0	70.0	79.0	80.5	71
Ice 5-5-55.5	do	68.5	81.0	79.5	88.0	92.5	74
Ice 5-10-55.5	do	39.5	72.5	56.5	78.5	71.5	70
Ice 5-15-55.5	do	20.0	34.0	34.0	37.5	36.5	50
Ice 5-5-57.5	do	8.5	50.0	46.0	52.5	61.0	50
Ice 5-10-57.5	do	0	3.0	15.0	3.5	8.5	13
5-5-51.5	do	93.5	94.5	94.5	94.5	94.5	81
5-10-51.5	do	89.5	96.0	91.5	97.0	95.0	85
5-15-51.5	do	91.0	94.0	91.5	95.5	95.0	79
5-5-53.5	do	87.0	92.0	92.5	92.5	93.0	82
5-10-53.5	do	67.0	85.0	90.5	92.0	92.5	75
5-15-53.5	do	21.5	62.0	62.5	67.0	80.0	66
5-5-55.5	do	21.5	73.0	62.0	72.5	81.5	66
5-10-55.5	do	0	12.5	9.5	12.5	30.0	40
Ice 13-5-51.5	Feb. 4	89.5	93.0	90.0	92.0	91.0	81
Ice 13-10-51.5	do	87.5	89.0	92.5	90.0	96.5	80
Ice 13-15-51.5	do	93.0	95.5	82.5	94.5	87.5	78
Ice 13-5-53.5	do	89.5	91.5	91.5	90.5	89.0	80
Ice 13-10-53.5	do	85.5	80.0	83.5	67.0	82.5	74
Ice 13-15-53.5	do	81.5	76.0	65.5	82.5	77.5	66
Ice 13-5-56	do	67.5	52.0	41.0	52.5	73.5	51
Ice 13-10-56	do	21.5	12.0	6.5	4.5	15.0	32
Ice 13-15-56	do	4.0	.5	0	1.5	1.0	7
13-5-51.5	do	93.5	93.0	95.0	93.5	92.5	82
13-10-51.5	do	93.0	86.5	89.5	94.5	89.5	79
13-15-51.5	do	88.0	88.5	91.0	92.0	88.5	74
13-5-53.5	do	90.5	88.0	90.0	91.5	89.5	69
13-10-53.5	do	90.0	....	76.0	....	80.5	58
13-15-53.5	do	74.5	58.5	47.5	60.0	72.0	49
13-5-56	do	18.0	2.0	0	14.0	65.0	22

RECOMMENDATIONS.

According to the experiments previously described, two methods gave a decrease of smut. The first of these, the roguing method, although it decreases the smut does not eliminate all of it, and is, moreover, impracticable in handling large fields or even in small fields, on account of the work which it involves. It is useful, however, in nursery plats where hybrid plants and small quantities of pedigreed seed are being raised and where injurious treatments would mean a loss of seed that could not be replaced. An attempt to use it in combination with a seed-plat method would require several years at least to eliminate all of the smut. It can not, therefore, be recommended as a treatment for general practice in preventing loose smut.

The second method is Jensen's modified hot-water treatment. This has been entirely successful. It can not at present be recommended for the treatment of seed for large areas, however, but in combination with a seed-plat system it is entirely practicable and its use can be urged for general farm practice.[a] Its application requires care and intelligence, and it can best be used with small lots of seed. In general, the method to be recommended is the following: The keeping of a seed plat the seed for which has been cleaned of smut by the application of Jensen's modified hot-water treatment and the use of the grain from this plat for seed the succeeding year, when no further treatment is necessary. If the farm is very large it may require several years to get the smut entirely eliminated from the whole farm. This recommendation involves two processes, which will now be described.

SELECTION OF THE SEED PLAT.

A good, clean, well-cultivated piece of land should be selected and set aside for the raising of seed for the succeeding year. For this plat seed should first be carefully cleaned and selected by the best fanning and sifting processes. This seed should then be treated as directed later. The plat ought to be large enough to provide at least twice as much grain as will be necessary for farm seed the following year, in order to allow for loss in cleaning and selecting. This seed plat must not be placed next to fields of smutted crops of the same cereals. The plat ought also to be located so that the prevailing winds at flowering time will not carry spores to the seed plat from a neighboring field of the same grain. The isolation of this plat from smutted crops of the same cereal is absolutely necessary, not only from crops on the owner's farm but from neighboring farms as well. A strip of wood, a cornfield, a large meadow, or a barley or oat field intervening between the wheat seed plat and fields of smutted wheat will be useful, and similarly a field of corn, oats, or wheat or a large meadow or strip of wood between the barley seed plat and the smutted field will be a valuable protection. This point can not be too strongly emphasized and the cooperation of neighbors may be necessary to carry it into effect.

TREATMENT OF THE SEED FOR THE SEED PLAT.

After seed for the plat has been properly cleaned it must be treated by the Jensen method to eliminate the smut. This can be done according to the following directions: The clean seed should be soaked for from five to seven hours in water at ordinary room temperature, 17 to 22° C. (63 to 72° F.). It should be placed in small, loose sacks or wire baskets containing not more than one-half peck each and drained for a short time. It is of the greatest importance that the seed be treated in small lots in order that all of the grain may be quickly and uniformly brought to the desired temperature. Two tubs or vats of water should be provided. In one tub (No. 2) the exact temperature required should be maintained. The other tub (No. 1) is used for bringing the grain to the temperature of the treatment, so as not to lower the temperature in tub No. 2. Galvanized-iron tubs of 20 to 40 gallons capacity and kerosene or gasoline double-burner stoves are sufficient for treatment. The drained sacks or baskets of seed should be plunged into tub No. 1 for a minute, then transferred to tub No. 2, and kept agitated while immersed at temperatures and for the periods specified below, the temperatures mentioned being maintained as nearly as possible:

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[a] It may be possible to construct machines to make a general farm practice of treatment of large lots of seed possible, but none such is at present on the market.

For barley, 15 minutes at 52° C. (125.6° F.).
For wheat, 10 minutes at 54° C. (129.2° F.).

In treating barley, if the temperature should rise above 52° C. (125.6° F.) the time of immersion must be reduced to ten minutes at 53° C. (127.4° F.) or five minutes at 54° C. (129.2° F.). Above 54° C. (129.2° F.) there is no safe margin. If the temperature falls slightly below 52° C. (125.6° F.) the time of treatment should be increased in proportion. A temperature lower than 51° C. (123.8° F.) will not be effective. In treating wheat, if the temperature should rise above 54° C. (129.2° F.) or fall below 52° C. (125.6° F.), the time for immersion must be diminished or increased accordingly. Under no circumstances should a temperature of more than 55° C. (131° F.) be allowed. Temperatures below 51° C. (123.8° F.) are ineffective.[a]

Seed treated as indicated may be planted as soon as it is sufficiently dry to run freely through the drills. Allowance must then be made for the swollen seed and also for injury in treatment. The increase due to swollen seed can be estimated by measuring seed before and after treatment. The seed may be treated several months before seeding time and then dried quickly and carefully. In many cases the grain germinates as well or better when rested after treatment than if sown immediately. The seed may be dried by spreading it out in thin layers not over 2 inches in depth on a clean granary floor or on canvas and shoveling or raking it from time to time. It must not be allowed to sprout. Care must be taken to prevent the freezing of the grain when it is moist, as this will impair germination.

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[a] Two men working together can easily treat one bushel of grain an hour, or enough seed in one day to sow a seed plat from 6 to 10 acres in size.

A good thermometer should be used for all treatments.[a] The use of an instrument which is not accurate will result in injury to the germinating power of the grain on the one hand or in failure to prevent the smut on the other.

Several weeks before sowing, the seed should be tested for germination. This can be done by placing several small lots of grain of 100 seeds each between damp blotters and keeping them at a living-room temperature for several days. The percentage of sprouted kernels will show the power of germination. If this is low, a corresponding increase in the rate of seeding is necessary.

The seed plat should be maintained from year to year, at least as long as any smut is present on the farm. Seed obtained from the treated seed plat does not have to be treated the following year. All fields that are free from smut must be kept separated, as previously stated, from smutted fields of the same grain. Cooperation with neighbors may be necessary to bring this about.

SUMMARY.

The loose smuts of wheat and barley demand treatment in many sections of the United States on account of their wide distribution, evident increase, and possible virulence, and on account of the difficulty of preventing them.

The loose smuts of wheat, barley, and wild barley are distinct species and are not interchangeable as to their host plants.

The loose smuts of wheat and barley infect the plant in the flowering stage and enter the embryo inside of the ovary before the latter ripens into the seed. An infected seed develops a smutted plant the following year.

Varietal differences in susceptibility to these smuts have been observed in both wheat and barley, but no immunity of marked practical value has been discovered. There apparently is no constant relationship between susceptibility and earliness of ripening.

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[a] Thermometers may be submitted to the Bureau of Standards, Washington, D. C., for test. A charge of about 50 cents will be made for testing at the two points necessary. They should be graduated in single or half degrees—centigrade—directly upon the stem or upon a scale contained within the stem, and should preferably read from 0° to 100°. The bulbs, at least, should be made of a suitable glass, such as Jena "Normal" thermometer glass or Corning Medium thermometer glass, in order that the readings may not change with time, and the general construction of the thermometer should be good. However, thermometers with the Bureau of Standard's certificates can be purchased directly from manufacturers or large dealers, and this is generally a much more convenient way to secure them, because it avoids the risk and expense of shipping them to and from Washington.

Artificial inoculations of flowers with loose smut from the time when the stamens are still green to the time when the ovary is one-third its mature size are usually successful. The optimum period for artificial inoculation is at the time when the flower is in full bloom or when the ovary is just commencing to develop after fertilization.

The time of maximum smut in a field of wheat or barley corresponds exactly with the full flowering period of the crop.

The partial smutting of plants and of heads is common; this is possibly associated with the time of inoculation or with weather conditions. Sound grains on partially smutted heads are not infected by the mycelium growing inside the plants on which the seeds are formed.

The time of planting of spring wheats and barleys had no effect on the loose smuts at St. Anthony Park, Minn. In winter barleys at Amarillo, Tex., however, very late planting resulted in almost no smut, while planting at the ordinary time or earlier in the season resulted in a large amount of smut. The absence of smut on the late plantings is probably due to a difference in optimum temperature for the internal smut and the seed germinations.

The effects of Jensen's method on the germination of wheat and barley for different periods of previous soaking and for different temperatures and time limits are shown in Tables V and VI. In general the germination is injured, though variously, according to the severity of the treatments.

The effects of Jensen's method on the loose smut of wheat and barley for different periods of previous soaking, different temperatures, and times of treatment are shown in Tables VII and VIII. The best treatments are the following: For barley, a soaking in cold water for five hours, followed by a soaking in hot water for fifteen minutes at a temperature of 52° C.; for wheat, a soaking in cold water for five hours, followed by a soaking in hot water for ten minutes at a temperature of 54° C. These treatments if carefully carried out entirely prevent the smut and produce only slight injury to the germination of the seed.

Thorough drying of the seed after the application of Jensen's modified hot-water treatment is not injurious to the germination. When seed is injured by the treatment, the germination improves after several weeks of drying, and continues to improve for at least two months. (See Tables VIII, XIII, and XIV, and fig. 2.)

Soaking the seed in ice water previous to the hot-water treatment is not as efficient against smut as soaking in cold water at ordinary temperatures.

The application of Jensen's modified hot-water treatment will result in a decrease in yield, unless an allowance for slightly injured germination is made in sowing. With the best treatments the decrease is very small.

Picking out the loose smut of wheat and barley decreases smut even without isolation of the plat; the decrease is more marked, however, when the plat is isolated. The roguing method is nevertheless impracticable in farm practice on account of the time required and because it does not completely clean out the smut. It is useful, however, in breeding plats.

The treatment of wheat and barley seed with formalin has no effect on the loose smut. The use of formalin will, however, completely prevent covered smut of barley and bunt of wheat.

All smuts of wheat and barley, including bunt and loose smut of wheat and covered and loose smut of barley, were practically eliminated from a 30-acre experimental farm in one year by the use of Jensen's modified hot-water treatment. This method can therefore be used on a fairly large scale where accuracy and care are employed.

The following method for farm practice is recommended: Grow seed in a small isolated seed plat, using clean, heavy seed of the best quality and of pure stock. Treat this seed carefully by Jensen's modified hot-water method as recommended in this bulletin and sow the seed according to germination tests. Plant the seed from the seed plat the following year for the general farm crop. Maintain the seed plat every year.

PLATES.

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DESCRIPTION OF PLATES.

[The photographs for all plates were made by Mr. H. D. Ayer, Minnesota Agricultural Experiment Station, St. Anthony Park, Minn.]

PLATE I. Heads of wheat and barley, showing the common smuts. *a*, Bunt or stinking smut of wheat (Fife) ; head to the right with glumes removed to show smutted kernels (smut balls) in place; two whole and two broken smut balls shown below. *b*. A sound head of wheat (Minnesota No. 188), with sound grains shown below. *c*. Loose smut of wheat (Minnesota No. 188) ; to the right a head from which all of the spores have been blown, leaving the bare stalk. *d*, Two heads of covered smut of barley (Minnesota No. 105). *e*, A sound head of barley. *f*, Loose smut of barley; to the right a head from which the spores have been blown.

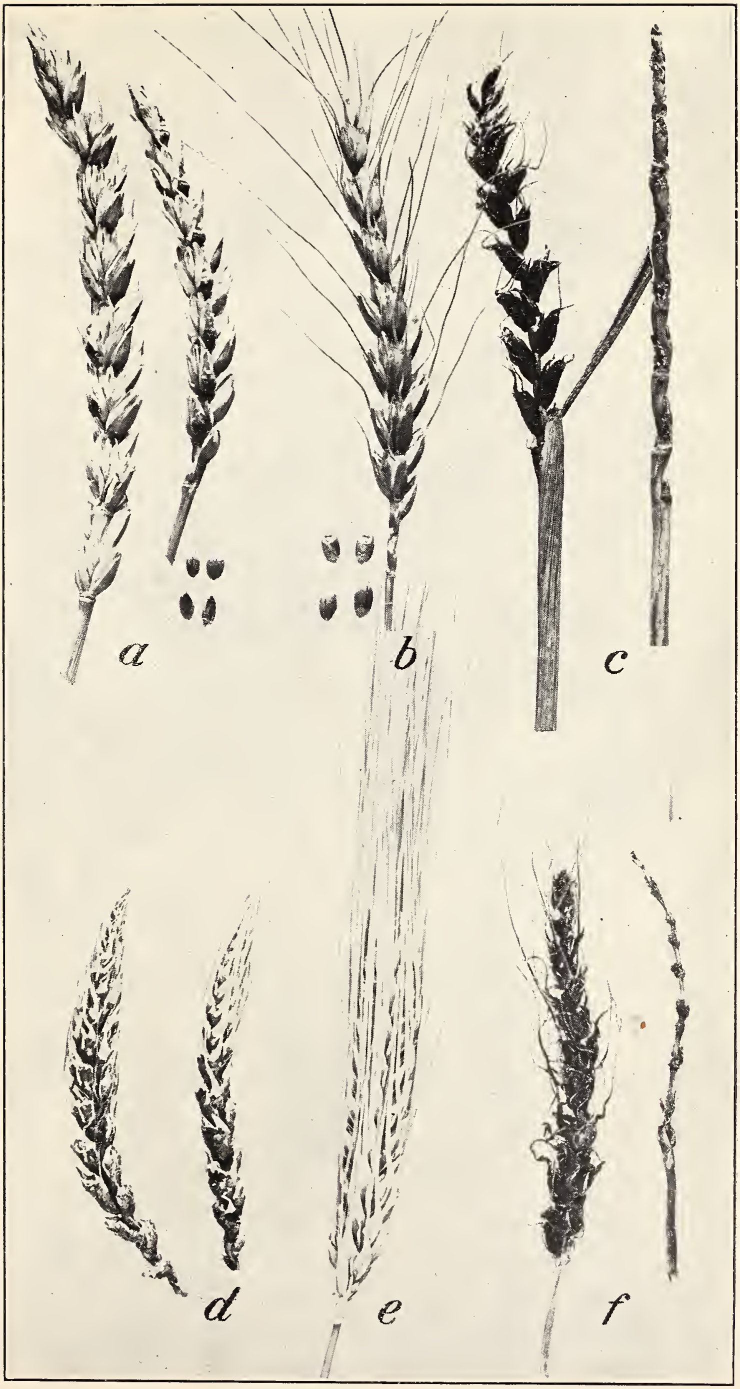
PLATE II. Loose smut of barley (Minnesota No. 105), showing the various stages in the development of a smutted head. *a*, Head just appearing in the boot (sheath) ; *b*, half out of the boot; *c*, mature in size, but not yet distributing spores; *d*, smut mass broken and distributing spores; *e*, all of the spores blown off and the bare stalk of the head left.

PLATE III. Loose smut of barley (Minnesota No. 105). showing various manifestations of smut. *a*, Sound head; *b*. partially smutted head. upper spikelets sound; *c*. completely smutted and mature head. showing powdery mass of smut; *d*. smut head formed late in the season and never developing a powdery mass of spores; *e*. a badly smutted head. showing a smutted bract at the base of head.

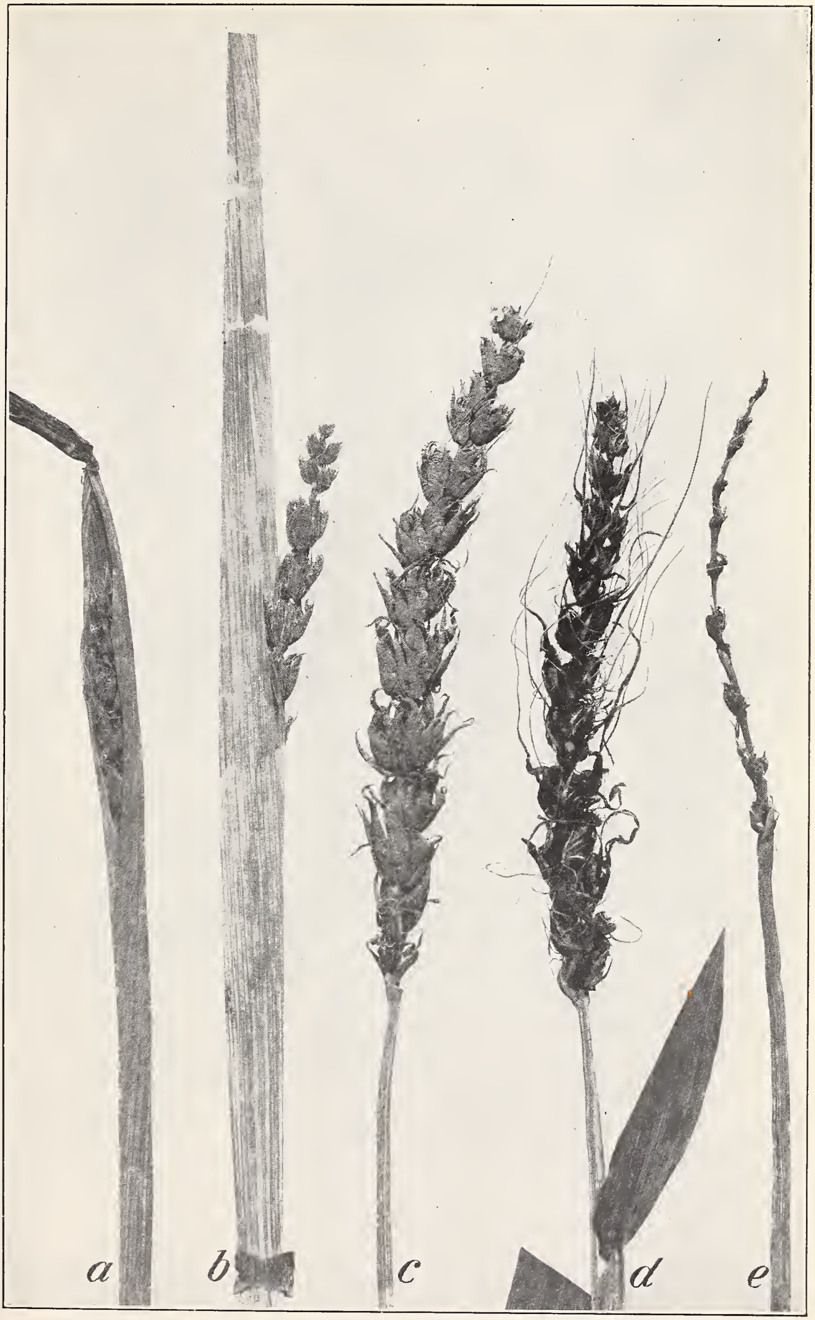
PLATE IV. Loose smut of wheat. showing the various stages in the development of a smutted head as described for barley in Plate II. The smut is broken into powdery masses as soon as the head emerges from the boot. (Compare with Plate II.)

PLATE V. Loose smut of wheat (Minnesota No. 188). *a*, All of the heads of one sound plant—all sound; *b*, all of the heads of one smutted plant—all smutted; *c*, a partially smutted head of wheat—upper spikelets sound.

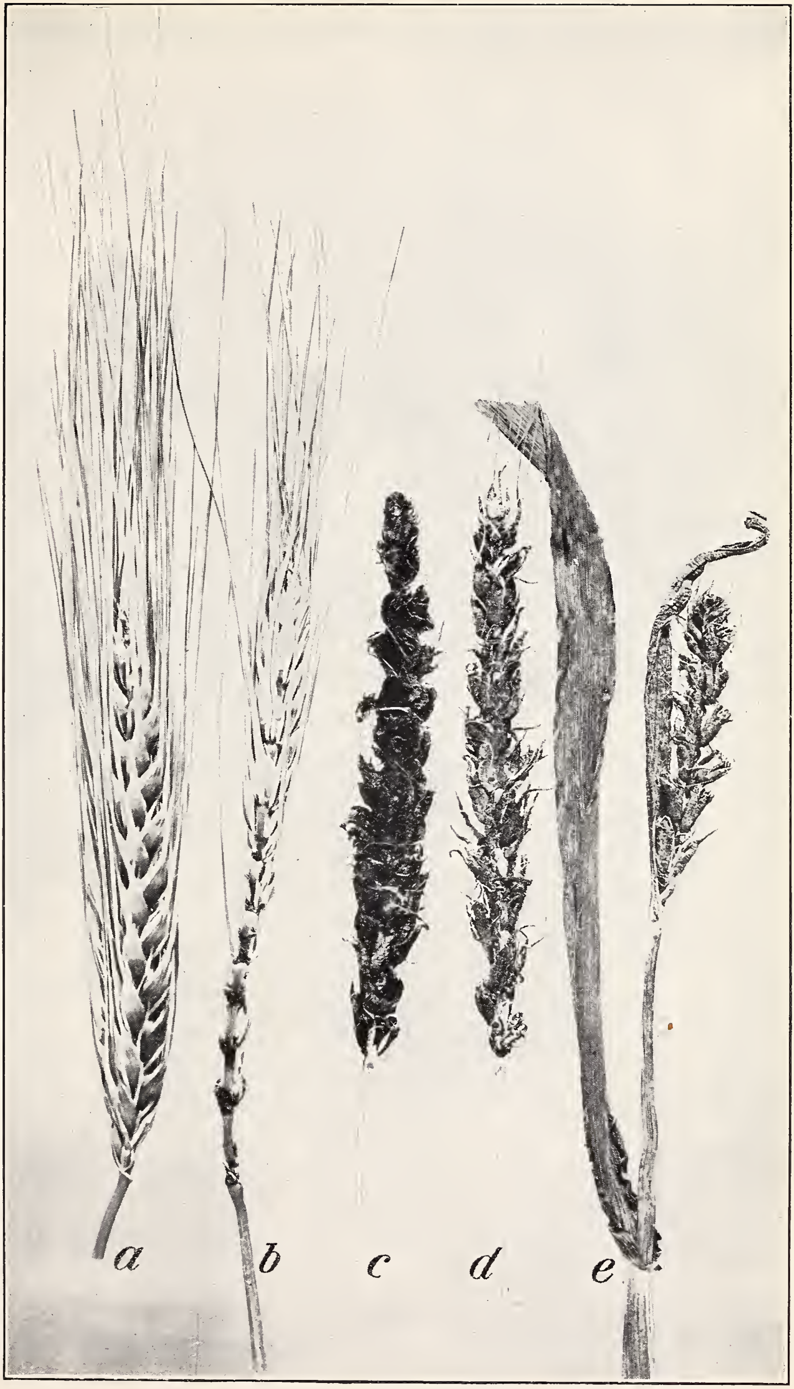
PLATE VI. Loose smut of barley (Minnesota No. 105). Upper row—all of the heads of one sound plant—all sound: lower row to the left—all of the heads of one smutted plant—all smutted; lower row to the right—all of the heads of a partially smutted plant—six smutted and one sound.



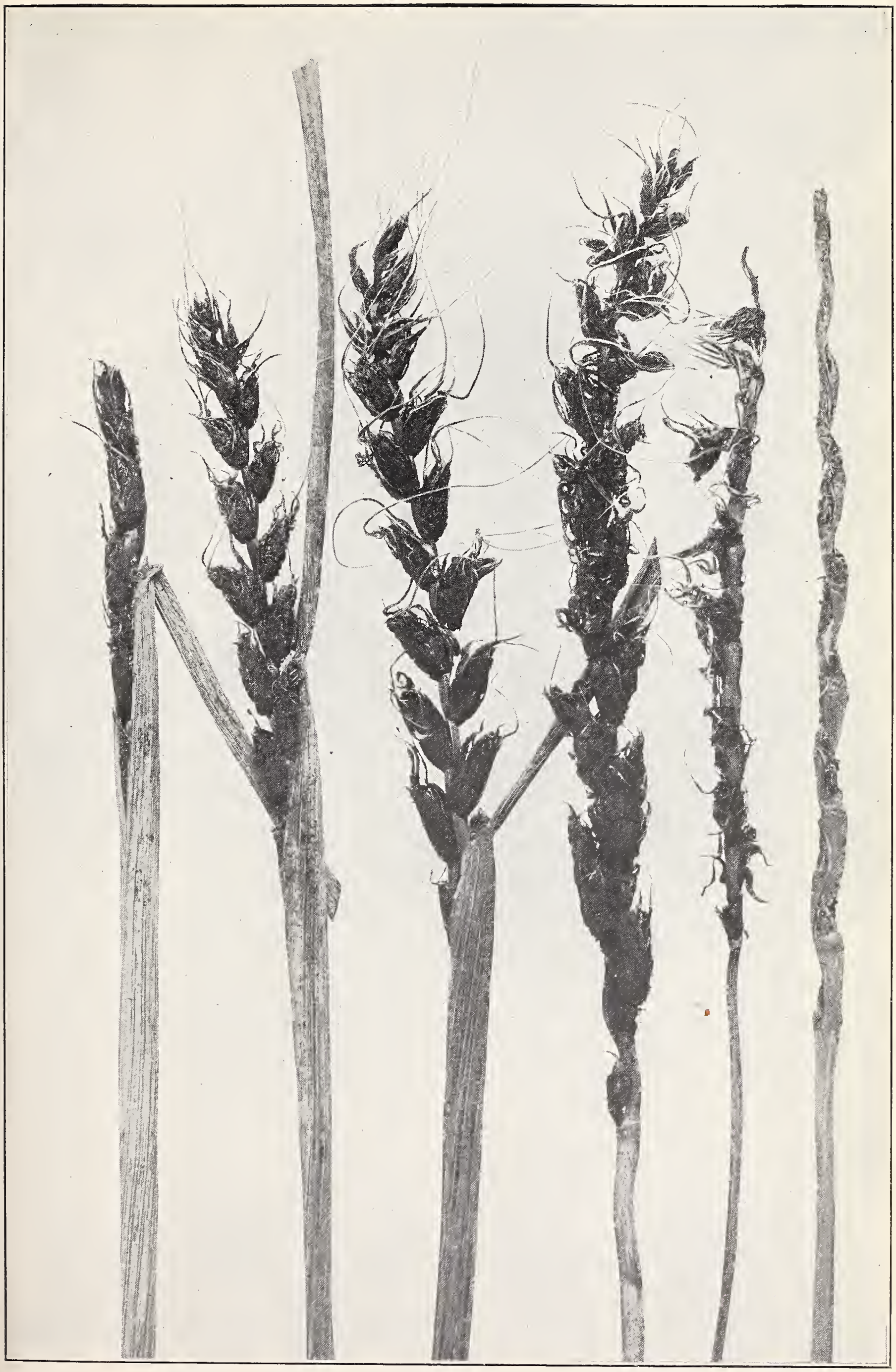
HEADS OF WHEAT AND BARLEY, SHOWING THE COMMON SMUTS.



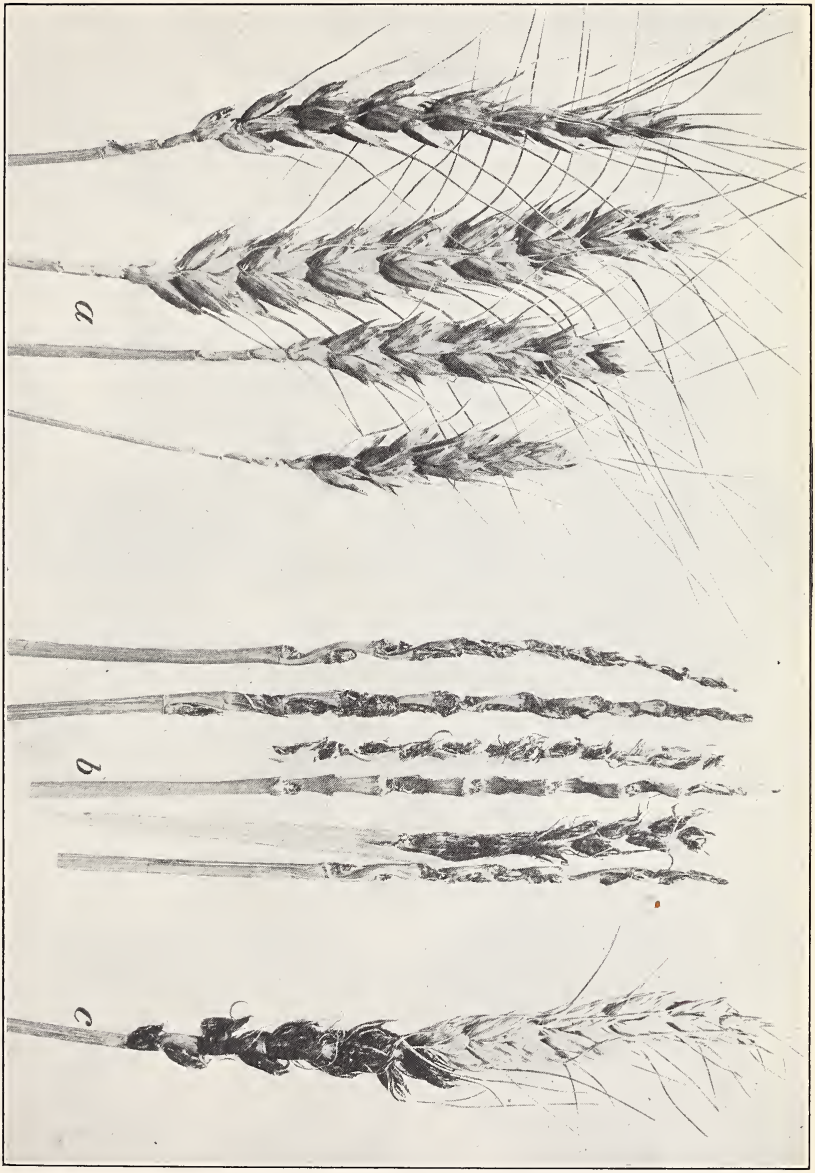
LOOSE SMUT OF BARLEY, SHOWING THE VARIOUS STAGES IN THE DEVELOPMENT OF A SMUTTED HEAD.



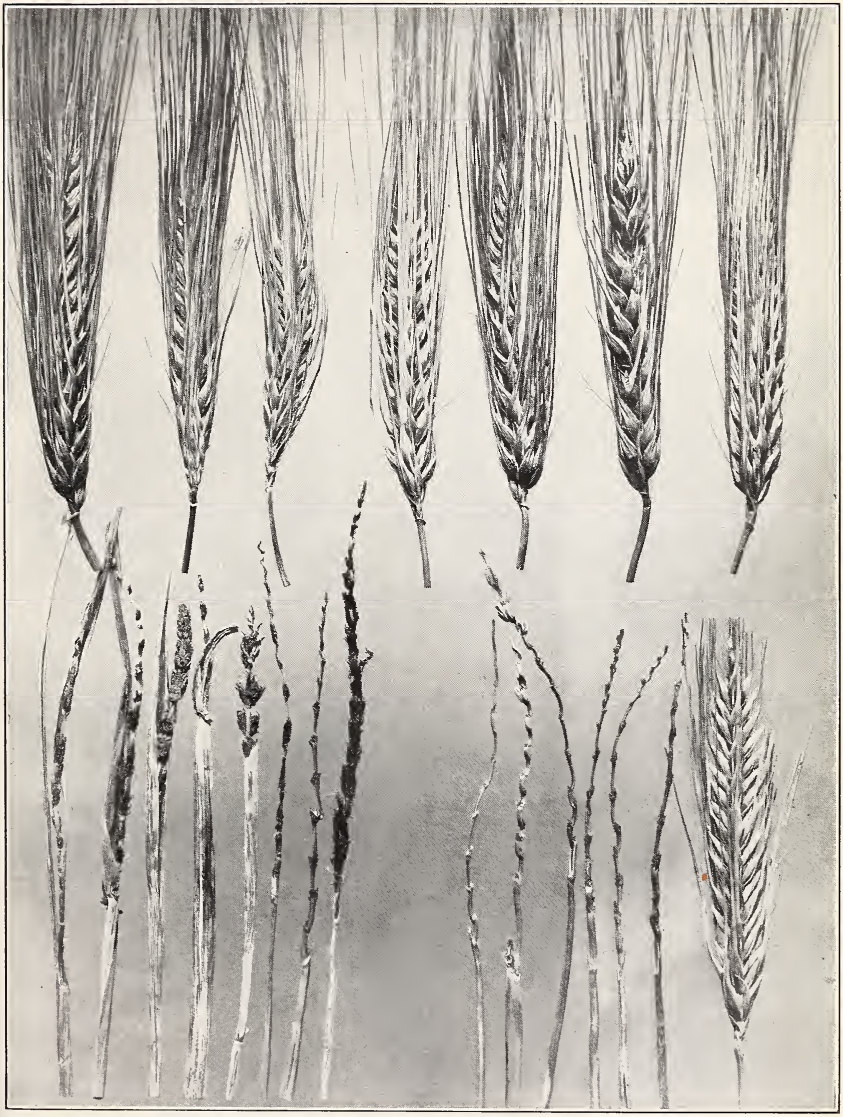
LOOSE SMUT OF BARLEY, SHOWING VARIOUS MANIFESTATIONS OF SMUT.



LOOSE SMUT OF WHEAT, SHOWING THE VARIOUS STAGES IN THE DEVELOPMENT OF A SMUTTED HEAD.



LOOSE SMUT OF WHEAT, SHOWING HEADS FROM A SOUND PLANT AND FROM A SMUTTED PLANT AND A PARTIALLY SMUTTED HEAD.



LOOSE SMUT OF BARLEY, SHOWING HEADS FROM A SOUND PLANT, A SMUTTED PLANT, AND A PARTIALLY SMUTTED PLANT.

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